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REPAIR PROCESS IMPROVEMENT AT THE OGDEN AIR LOGISTICS CENTER, LANDING GEAR DIVISION: A CASE STUDY IN THE APPLICATION OF THE THEORY OF CONSTRAINTS

THESIS

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The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

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Abstract

This study explored the nature and extent of success that resulted from the implementation of the Theory of Constraints (TOC) in a depot repair environment. The actions taken to implement TOC were determined. Performance measures which defined success were identified and data was collected and summarized to demonstrate performance before and after implementation of TOC concepts. Improvements in flowdays and work-in-process (WIP) were determined to be attributable to the TOC effort. In addition, the unique characteristics of probabalistic repair and supply system variability were noted as those characteristics that posed the greatest challenges to implementing TOC in a remanufacturing environment. Despite these challenges, analysis revealed that the Landing Gear Division at Ogden Air Logistics Center (ALC) successfully implemented TOC concepts and improved performance within the wheel repair process in terms of the performance measures defined.

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I. Introduction

Background

The Air Force has made a commitment to implement Total Quality Management (TQM) and change the culture of the workforce to focus on the customer. Many view the philosophy of TQM, when supported by appropriate tools of implementation, as the means for realizing the needed increases in organizational and individual efficiency and effectiveness. To achieve increased efficiency and effectiveness, continuous process improvement, a basic TQM principle, is employed. Numerous organizations in the USAF are currently in some phase of training or application of principles of process improvement (Simons and Moore, 1992:1).

Continuous process improvement is an admirable concept, but remains just that - a concept, without specific tools to practically implement process improvement. There exists a general lack of strategy to link together the continuous process improvement philosophy with a means of implementation. In its efforts to seek ideas which will enhance the effectiveness of TQM, the Air Force is beginning to apply the Theory of Constraints (TOC), a concept which is growing in recognition and popularity throughout industry (Simons and Moore, 1992:1-2).

The Theory of Constraints (TOC) is a management philosophy developed by Eliyahu M. Goldratt. It emphasizes constraint identification and exploitation as the key to focusing limited time and resources on processes to achieve the greatest potential returns (Umble and Spoede, 1991:26). Originally seen as a competitor of TQM, it is now viewed by many as a "missing link" in many of the improvement efforts being undertaken throughout the Air Force. TOC complements TQM by focusing improvement efforts on the weakest elements of a process. In essence, it provides a means of systematically achieving continuous process improvement (Simons and Moore, 1992:1-2).

Within the past year, the Air Force Materiel Command (AFMC) has established a Metrics Program Management/Theory of Constraints Office to oversee TOC training and applications. Approximately 370 AFMC mid-and upper-level managers have received extensive training in TOC at a cost of nearly $990,000 for direct training expenses which do not include TDY costs or salaries. These figures include training for 40 general officers. In addition, 75 individuals have received training in the form of 2-day functional education workshops at a cost of approximately $13,500. As a result, senior managers are interested in examples of the practical application of TOC in the Air Force and, in particular, in AFMC (Swartz, 1993).

AFMC is pursuing a variety of initiatives to integrate the fundamental concepts of TOC into logistics and production/repair methods (Simons and Moore, 1992:1). One of the most notable applications of TOC for improving repair processes is in the Landing Gear Division at Ogden Air Logistics Center (ALC), Hill AFB, Utah.

According to Captain Steve Swartz of the HQ AFMC Metrics Program Management/Theory of Constraints Office, although there have been several articles and papers written and presented concerning commercial manufacturing applications of TOC, there is still a void in terms of validating TOC application efforts and results. In addition, many of the existing validation efforts have been conducted by the Goldratt Institute and may not constitute truly independent looks at what happened in order to validate the results claimed (Swartz, 1993).

Little or nothing has been written about applications of TOC in the remanufacturing environment of Air Force depots. Consequently, there is a need to examine and validate the efforts and results of TOC applications such as at the Ogden ALC Landing Gear Division (Swartz, 1993).

Research Objective and Investigative Questions

The objective of this research is to validate the nature and extent of success in implementing Theory of Constraints procedures in the remanufacturing environment at the Ogden ALC Landing Gear Division (OO-ALC/LIL). To accomplish this, the following five investigative questions were asked:

1. What was done to implement TOC at OO-ALC/LIL?
2. How was performance success defined and measured?
3. What was the performance of OO-ALC/LIL before and after TOC implementation?
4. Can the changes in performance be reasonably attributed to TOC implementation?
5. What are the unique characteristics of the remanufacturing environment which affect TOC implementation success?

Scope and Limitations

Because only the Ogden ALC Landing Gear Division was examined as a single case study of the application of TOC, the insights gained from this application of TOC are specific to the landing gear repair process at Ogden. Therefore, conclusions and recommendations may only directly apply to this particular division and depot. Nonetheless, the general findings may provide useful information for other depots.

Concept Definitions

To assist in general understanding of the objective of this research and the accompanying investigative questions, the definitions of eleven key terms are provided:

> **Total Quality Management (TQM)** is a comprehensive, customer-focused system that many organizations are adopting to improve the quality of their products and services. It is a way of managing the organization at all levels, top management to front-line, to achieve customer satisfaction by involving all employees in continuously improving the work processes of the organization. (Federal Quality Institute, 1991:1)

> **Theory of Constraints (TOC)** is a philosophy of management and a set of approaches for implementing this philosophy. It is largely the work of one man, Dr. Eliyahu M. Goldratt. The TOC philosophy provides a precise focus on the goals of an organization and on the constraints that limit the accomplishment of those goals. (Demmy and Petrini, 1992:6)

> A system **constraint** is anything that limits a system from achieving higher performance versus its goal. (Goldratt, 1990:4)

> A **bottleneck** is defined as any resource whose capacity is equal to or less than the demand placed upon it. (Umble and Srikanth, 1990:65)

A **capacity-constrained resource (CCR)** is any resource which, if not properly scheduled and managed, is likely to cause the actual flow of product through the plant to deviate from the planned product flow. (Umble and Srikanth, 1990:67)

The **drum** is the major capacity constraint resource. Its production rate serves as the drumbeat for the entire production system. (Goldratt and Fox, 1986:98)

A **buffer** is inventory placed in front of a capacity constraint resource to keep the resource busy during the next predetermined time interval, protecting the throughput of the system against any disruption that can be overcome within the predetermined time interval. (Goldratt and Fox, 1986:98)

The **rope** is a means of communication between the capacity constraint resource and the first operation where materials are inducted into the system. This rope ensures that materials are released into the system at the rate at which the capacity constraint resource produces and also ensures that inventory does not grow beyond the level dictated by the buffer. (Goldratt and Fox, 1986:98)

Throughput is the rate at which the system generates money through sales. (Goldratt and Fox, 1986:28)

Inventory represents all the money the system invests in purchasing things the system intends to sell. (Goldratt and Fox, 1986:28)

Operating Expense includes all the money the system spends in turning inventory into throughput. (Goldratt and Fox, 1986:28)

Overview

The literature review in Chapter II addresses the generally accepted procedures for TOC implementation and presents a summary of literature written previously which is pertinent to this study. Chapter III presents the research methodology, establishing the plan for answering investigative questions one through five. Details of the plan are revealed in a discussion of research design, research methods, quality considerations, sample selection, data collection, and data analysis techniques. Chapter IV is the case write-up. The analysis of data collected and the results of this analysis are contained in Chapter V. Chapter VI summarizes the material presented, making conclusions and recommendations for further study.

II. Literature Review

A review of literature is presented to establish better understanding of the background issues involved in this case study. The review examined the environmental factors that prompted the Landing Gear Division at Ogden to implement TOC procedures, presenting previous improvement efforts as well. The literature review also focused on the basics of TOC and its applicability in a remanufacturing environment. Additionally, the Air Force Materiel Command's experiences with TOC were reviewed. Finally, the review of literature examined what has been written about TOC to determine if previous validation efforts have been undertaken.

Environmental Factors

The environmental factors that prompted the management of the Landing Gear Division to seek ways to improve their operations are not unique to the Ogden Air Logistics Center. Air Force wide, maintenance depots are experiencing significant changes that are challenging the "business as usual" approach to the mission (Simons and Moore, 1992:1). These changes include 1) the shrinking of financial and personnel resources due to defense budget cuts; 2) the reorganization of the depots into the product line structure due to the streamlining effort in FY90-91; 3) potential depot and base closures to achieve defense infrastructure drawdowns due to the dismantling of the former Soviet Union and the corresponding threat reduction; and 4) the competition of weapon system and component repair workloads with other providers of maintenance and support services due to the Defense Management Review Board's Defense Management Review Decision (DMRD) 908, "Strengthening Depot Level

Maintenance" (Rigsbee and West, 1992:25). Adding to this confusion are policy changes such as the stock funding of depot level reparables, unit costing, and fee for services (Moore, 1991:35).

The Air Force envisions competition for workloads as the key strategy for achieving the mandated long-term savings of DMRD 908, while retaining the depot infrastructure and capability, and managing the downsizing of the military forces without a degradation of the readiness of the remaining forces. For the Air Force Materiel Command, the total savings mandated for FY91-97 is $1.32B. Approximately 80% of the total savings, or $1.06B, is expected to be achieved from actual competition and applying the lessons learned from these competitions to other workloads to reduce the cost of repair to AFMC customers (Rigsbee and West, 1992:25).

The Ogden ALC depot maintenance organization did not fair well in the first round of workload competition during FY91. The F16 A/B/C/D operational flight program workload, with a contract value of $1.5M, was awarded to private industry in September 1991. In FY92, the candidates for workload competition were the F16 APG-66 radar, the Minuteman III software and nuclear hardness, and miscellaneous landing gear. The estimated total annual value of these candidate workloads was $39M (Rigsbee and West, 1992:25). The F16 APG-66 radar and the Minuteman III software and nuclear hardness workloads were awarded to private industry, and the miscellaneous landing gear workload remained with the depot (Wood, 1993). The impact of future competitions, as well as workload assignments, will have a direct bearing on whether the ALCs gain workloads and grow, or lose workloads and shrink. Thus, Ogden ALC is strongly motivated to take a critical look at their industrial processes with the objective of improving competitiveness by reducing costs and increasing effectiveness.

Previous Process Improvement Efforts

Total Quality Management (TQM) principles, and in particular, the empowerment of the people, are viewed by many Air Force leaders as the best opportunity for the Air Force to succeed in achieving "continuous process improvement" and thus, gain the needed competitive edge. All too often though, personal innovation and initiative have targeted opportunities for process improvement that have had minimal impact on overall mission effectiveness. Some improvement results have lead to the enhancement of efficiency and effectiveness of one office or section at the expense of others, creating a "suboptimization" effect. These improvement efforts, in the name of TQM, have highlighted the lack of a strategy that links the philosophy of TQM with the application of practical continuous process improvement tools. TOC has been described by both its proponents and users as a necessary complement to TQM, serving as a practical means to achieve continuous process improvement in a production environment (Simons and Moore, 1992:1).

Theory of Constraints

TOC complements TQM by focusing improvement efforts on the weakest process in the "chain" of interdependent processes which comprises the total system. The weakest process, i.e. the one which most limits goal achievement, is defined as the system's constraint or bottleneck. The greatest potential for achieving the overall goal of the system is to focus improvement efforts on this constraint. The overall goal is expressed in terms of measurements that permit the development of operational rules. These measures are throughput, inventory, and operating expense. Traditional TOC literature defines the overall goal as "making money." Throughput is defined as the rate at which a system generates money through sales as opposed to through production. Something produced, but not sold is not considered to be throughput. All the money that a system has invested in procuring things intended to be sold is inventory. This view of inventory excludes the added value of labor and overhead. Operating expense includes all the money spent to turn inventory into throughput. This definition includes both direct and indirect labor (Goldratt and Cox, 1992:58-60).

The fundamental steps to focus improvement efforts for the greatest impact on achieving the overall goal (expressed in terms of throughput, inventory and operating expense) are called the five focusing steps of TOC. These steps are as follows (Goldratt and Cox, 1992:303):

1. Identify the system constraint.
2. Exploit the system constraint.
3. Subordinate everything else to the constraint.
4. Elevate the system constraint.
5. If, in the previous steps, a constraint has been broken, go back to the first step. Do not let inertia cause a system constraint.

In identifying the system constraint, those processes, resources, or procedures which keep the system from achieving its goal with greater success are examined. Of course, a clearly defined goal is necessary before such an examination can be accomplished. Incorrectly identifying the system constraint will preclude the success of the improvement effort. A constraint can be physical, financial, or even procedural (Simons and Moore, 1992:2).

Constraints can be found in a variety of ways, including using intuition. Process flows, work flows, or material flows are examined to find the system constraint. Backlogs of work and inventory, late jobs, and areas receiving high expeditor interest are all symptoms which might indicate where a system constraint can be found (Simons and Moore, 1992:2).

Regardless of how the system constraint is found, it is necessary to validate the belief that something is a constraint. With resource constraints, this can be done by comparing the capacity of the resource with the demand placed on it. If the demand placed on a resource is not 100 percent or more, then it is not a constraint. The management of a resource may turn into a constraint, in which case the constraint is one of policy (Simons and Moore, 1992:2).

Exploiting the system constraint involves ensuring that the constraint is being used as intelligently as possible. Awareness of the existence of the constraint which limits the ability of the system to achieve its goal facilitates recognition that any opportunity lost in the utilization of the constraint reduces the potential of the entire system. With this in mind, exploiting the constraint begins with ensuring that the constraint is fully utilized for production by removing nonessential activities, having work completely prepared in advance for processing by the constraint, and by off-loading processing that can be done elsewhere. Lost utilization time at a constraint represents a corresponding decrease in the achievement of the entire system (Simons and Moore, 1992:2-3).

Exploitation does not end with keeping the constraint busy. If demand for the resource exceeds capacity, then priorities must be examined. The constraint should be used to work the most important things for which it can be used (Simons and Moore, 1992:3).

When the constraint is an internal policy, simply revising the policy may be the answer; however, with an external constraint, exploitation may seem elusive. Nevertheless, the logic which applies follows that of a physical constraint. Exploitation of a policy constraint involves seeking ways to minimize the extent to which the policy constrains the system. Initially, the policy in question must be fully understood in terms of its intent, what it actually imposes, and perceptions of the policy. Studying a policy to find these things out may reveal that actions perceived to be in conflict with the policy are, in reality, not in conflict and that more judicious application of the policy is required (Simons and Moore, 1992:3).

Minimizing the impact of an external policy constraint on operations requires actions such as those that would be taken when dealing with physical constraints since policy constraints effectively turn otherwise non-constrained resources into constraints. Recall that these types of actions generally focus on keeping the constrained resource fully utilized, working on those activities which are most important in terms of system throughput (Simons and Moore, 1992:3).

Subordinating everything else to the constraint or the decisions made in step 2 to exploit the constraint involves trying to use everything else in the system in a way which supports the effectiveness of the constraint. Examples of this can include actions to ensure that the use of non-constraints enhances the ability of the constraint to work on what is most important. Examples can also include not doing things which do not directly contribute to the goal. In other words, if a resource is not a constraint, utilization should be at the level that is necessary to keep the constraint fully utilized, even if that utilization level is only 50 percent (Simons and Moore, 1992:3-4).

Elevating the system constraint involves lessening the severity of the constraint by increasing its capacity. Only after all efforts have been made to exploit the constraint and subordinate the rest of the system to this exploitation should actions that involve sinking money into the system be considered. These actions include such things as buying more machines; hiring more people; and, in the case of policy constraints, revising or eliminating the policy (Simons and Moore, 1992:4).

Recycling through the first four steps ensures that inertia does not set in and facilitates continuous improvement. The actions taken previously may have caused the constraint to become a non-constraint. Likewise, a previous non-constraint may now be a constraint limiting the ability to continue to improve. In addition, this recycling through the steps is important because it allows managers to continue to evaluate the circumstances in which a particular system operates. With rapidly changing environments and changing goals this allows for adaptation which may be a key to survival (Simons and Moore, 1992:4).

Drum-Buffer-Rope

Related to the five focusing steps is a scheduling concept used to manage (synchronize) production operations, called the drum-buffer-rope (DBR) production management application of TOC. The drum is the exploitation of the system's constraint that "beats" the pace for the production rate of the entire system. The constraint can be a resource, a scarce raw material, the market demand, or a management policy. Often, a drum must include a detailed schedule of the constraint to ensure its exploitation (Schragenheim and Ronen, 1990:18).

The buffers are inventory within the system which ensure that the constraint will be kept busy during each predetermined time interval (Goldratt and Fox, 1986:98). In other words, a buffer is protection used to protect something from adjacent disruptions in flow that might adversely affect throughput. This protection is translated into time units with parts planned to reach the protected area some time before they are scheduled to be processed. Disruptions may be the result of breakdowns, varying setup times, absent employees, vendor problems, or simply the unavailability of some resource because it is busy with other jobs. Only critical areas that need protection require planned buffers. Of course, the drum is a critical area that should be protected from disruptions on adjacent operations (Schragenheim and Ronen, 1990:18).

Three types of buffers are used in DBR scheduling. A constraint buffer protects the throughput of the constraint, assuring the constraint is always busy. A shipping buffer protects the integrity of promised due dates, providing protection from possible disruptions at or following the constraint. An assembly buffer places non-constraint parts at assembly points downstream from the constraint, providing assurance that constraint produced parts are never delayed due to shortages of non-constraint parts (Demmy and Petrini, 1992:8).

The rope is the communication link from the drum to the point of material input to control the release of material into production (Goldratt and Fox, 1986:98). It is a mechanism to force all the parts of the system to work according to the pace of the drum and no more. This is accomplished by creating a detailed schedule for releasing material into the system (Schragenheim and Ronen, 1990:18).

The same benefits attributed to just-in-time (JIT) systems (shortened lead-times, reduced inventory, and higher quality) can be achieved with the DBR system without the need for micro management of less critical resources (Simons and Moore, 1992:5). The basic steps of DBR scheduling (synchronization) are 1) identify the constraints, 2) establish buffers to protect throughput, 3) schedule the constraint(s), 4) release materials to support production at the constraint, and 5) forward schedule work centers following the constraint to ensure due-date performance (Fawcett and Pearson, 1991:50).

Drum-Buffer-Rope in Depot Maintenance

Demmy and Petrini suggest that DBR scheduling is well suited for depot repair operations that have many job steps and physical movement of material from one workcenter to another. This would indicate that landing gear, wheels, and hydraulic cylinders repaired at Ogden ALC would be good candidates for the application of the DBR production management application of TOC. However, the remanufacturing environment of depot maintenance may require the standard procedures of TOC to be modified to deal with disassembly operations and with probabilistic repair (Demmy and Petrini, 1992:11).

When reparable assets are disassembled into their components, each component is subjected to cleaning and possibly several processing and nondestructive inspection operations. The precise operations required to return each of the recovered components to serviceable condition is determined in the evaluation and inspection step. This step also determines which components are not economical to repair and must be condemned and which components do not require any repair, but need only to be sent to serviceable inventories and used in reassembly. This process is a significant departure from the repetitive manufacturing environment where items are always built the same way (Demmy and Giambrone, 1990:9).

To successfully implement DBR in repair, Demmy and Petrini suggest that at least three areas unique to remanufacturing must be considered. First, they suggest that expected values must be used in the planning process and the estimates refined as inspection, diagnosis, and repair operations progress. Second, larger buffer inventories will be required due to higher levels of uncertainty and slow information feedback. Finally, delays in obtaining material from depot supply resulting in a lack of assurance of availability of repair parts and components must also be considered when sizing the buffer inventories (Demmy and Petrini, 1992:11).

AFMC's Experiences with TOC

Headquarters AFMC management has endorsed TOC concepts and has made Eliyahu M. Goldratt's book, The Goal, "required reading" for Air Force industrial managers. However, TOC has, to date, not been pushed as a mandated program or initiative with a formally sponsored "implementation plan." Instead, the command has allowed TOC applications to spread through the process improvement efforts of the TQM program. Headquarters' support for TOC has been primarily in the form of providing training and consulting resources to those managers taking independent actions to apply the concepts (Hinneburg, 1992:16).

AFMC has had reports of some significant improvements in operations as a result of TOC applications. In the area concerned with this case study, Demmy and Petrini reported that a process action team (PAT) at Ogden ALC used TOC concepts to develop new management methods for aircraft wheel repair. The claimed results were a 75% decrease in flow days and a 38% increase in throughput with no increase in staff or overtime. The only costs were to relocate several machines to form work cells. It is the purpose of this research to validate such claims of improvement in the area of wheel repair (Demmy and Petrini, 1992:6).

In addition, other successful applications within AFMC involving PAT teams using TOC concepts have been reported. But, as in the case of the Ogden ALC Landing Gear Division, these claims of success have not been independently validated. In accelerometer repair at the Aerospace Guidance and Metrology Center (AGMC), production of the Pendulous Integrated Gyroscopic Accelerometer increased from 35 to 47 per month while overtime decreased, quality improved, and unit repair cost was reduced from $1950 to about $1100 per unit. In the technical order distribution system at Warner-Robins ALC, the average daily production of technical orders was increased from an average production of 636 (for the 5 months preceding) to 1004. At San Antonio ALC, flowdays for processing engineering assistance requests decreased from 55 to 15 days and claims have been made of further reductions (down to about 5 days) resulting from currently proposed changes. In KC-135 overhaul at Oklahoma City ALC, the work on a KC-135 was reduced from a 7-day week to a 5-day week, resulting in considerable savings with no reduction of service to the customer (Demmy and Petrini, 1992:6). It is claimed that at Warner Robins ALC, TOC principles were used in a two product fastener manufacturing process before the system was in operation to assist in the initial design, startup, and early management which resulted in managers being better aware of what drives the system and the ability to surge production more smoothly and efficiently (Hinneburg, 1992:14-15). Finally, at Sacramento ALC, reduced flow times in the Manufacturing Services Division have been reported (Demmy and Petrini, 1992:6).

General TOC/DBR Literature

As with the AFMC experiences with TOC, little has been written validating industry experiences with TOC. Much of the literature found was very general in nature; dealing with theory, hypothetical applications, and simulations rather than validating claims of success.

Simulations/Models. Fry and Russell's research examined several strategies to determine how to best allocate capacity cushions (buffers) (Fry and Russell, 1993:1097, 1099). This article was reviewed because it discusses buffer allocation in a manufacturing process. As such, it had potential for providing insight concerning what was done to impleme TOC at Ogden's Landing Gear Division in terms of buffer sizing and location. Using a simulation methodology which models a hypothetical hybrid job-shop, differences between various allocation strategies and shapes of the allocation strategy across three levels of excess capacity and two levels of process fluctuations were determined. The results suggested that allocation strategy is dependent on the levels of process fluctuations in the manufacturing process (Fry and Russell, 1993:1097, 1099).

Management philosophies such as optimized production technology (OPT) and the theory of constraints (TOC) focus on identifying system constraints and exploiting them to improve the production process and achieve the system's goal. These methodologies provide a process to effectively manage material flow; however, they do not address economic outcomes of various alternatives. With this concern in mind, Ronen and Spector presented a graphic model which combines operational performance measures for analysis and design of operational systems (Ronen and Spector, 1992:2045-2048). The model was, in effect, the cost/utilization model developed by Borovits and Ein-

Dor (1977) applied to the analysis of production operations and materials flow. The model, which concentrated on the proportional cost and level of utilization of components of a system and on the system's constraints, was presented in simple graphic display. In addition to the graphic display, there were two parameters in the model which indicated the normalized index for the production system's balance and average utilization normalized to cost for the production system.(Ronen and Spector, 1992:2045-2048).

According to the authors, the model enables in-depth analysis of production systems. Graphical analysis of production systems with the model can identify and diagnose various situations, such as a faulty or dummy internal constraint, a plausible internal constraint, and a market constraint. A faulty internal constraint is a bottleneck caused by a relatively inexpensive component (machine, department, employee, subsystem) in the system, otherwise known as a policy constraint. A plausible internal constraint is an internal bottleneck caused by one of the system's more expensive components. A market constraint is an external constraint caused when demand for a product is less than the system's production capacity (Ronen and Spector, 1992:2048-2050).

The model also enables in-depth analysis of production processes over a period of time, according to the authors. In this manner the model can be used for making investment decisions concerning one or more system components, make-or-buy decisions, new product decisions, production discontinuation decisions, and strategic pricing decisions (Ronen and Spector, 1992:2051-2052).

The authors also promote the cost/utilization graphical analysis model as an effective tool when dealing with internal fluctuations caused at a particular station in a process or operation and cumulative fluctuations arriving from previous stations. It can be used with both the TQM approach to dealing with problem fluctuations and the TOC approach. Use of the model in this area can facilitate internal constraint positioning, reduction of internal fluctuations, and buffer planning (Ronen and Spector, 1992:2052-2057).

The model can also assist in evaluating different management philosophies, such as just-in-time (JIT), material requirements planning (MRP), TOC, group technology (GT), and TQM in a given case. According to Ronen and Spector, it can assist in studying the effect of these philosophies on shop floor planning and control, increasing throughput, and reducing fluctuations (Ronen and Spector, 1992:2058).

In summary, the authors adapted the cost/utilization model as a top- and middle-management decision-support tool and a control mechanism to assist in dealing with many of the same issues that Ogden might have addressed in applying TOC to the landing gear repair process: better location of a constraint resource, detecting faults in production planning, examining and finding the source of unwanted process fluctuations, managing buffers, assessing capacity, making wise production resource investment decisions, and identifying and prioritizing improvement areas (Ronen and Spector, 1992:2060).

Three major techniques for managing production and inventory are material requirements planning (MRP), kanban, and optimized production technology (OPT) (which is based on TOC). In MRP, inventory is "pushed" through the factory according to an external master schedule. Kanban, a "pull" system often termed just-in-time (JIT), allows a machine to produce a part only when authorized. This authorization comes when the downstream operator removes output parts and leaves a card. TOC is the basis for OPT or "squeeze" shop floor scheduling. It requires the identification of machines that are bottlenecks or constraints where production is "squeezed" and protects them with an inventory buffer to minimize the impact of normal fluctuations on the downstream dependent operations (Ramsay, Brown, and Tabibzadeh, 1990:39-40).

Ramsay, Brown, and Tabibzadeh developed a simple simulation model to test the applicability of these three major techniques for managing production and inventory in factories under different circumstances. The simulation model allows the essential differences between the techniques to be highlighted. Using the simulation model, test simulations were run and work-in-process (WIP) inventory levels were tracked. According to the authors, the "squeeze" approach (OPT or TOC) was shown to be the most useful of the three major production and inventory management techniques. This approach can include most of the features of "push" for scheduling upstream machines. The MRP term "safety stock" can be used interchangeably with the OPT term "inventory buffer". The fascinating aspect of the "squeeze" approach is that it focuses on something that the other two techniques overlook - the constraining resource(s) (Ramsay, Brown, and Tabibzadeh, 1990:39, 45).

This article provides further information about TOC as a follow-on for optimized production technology (OPT) and presented support for its use over other methods of managing production and inventory. As such, the article lends credibility to Ogden's basic decision to attempt to improve the landing gear repair process through the application of TOC.

Schragenheim and Ronen demonstrated the DBR approach with a computerized simulation example that produces a feasible and nearly optimal schedule. According to Schragenheim and Ronen, the three basic steps of DBR which are repeated every time the planning process is executed are 1) schedule and exploit the constraint(s) according to the organizational goal, 2) determine the buffer sizes, and 3) derive the materials release schedule according to the first two steps. In addition, two more general actions are taken whenever necessary. These actions are 1) identify the system constraints and 2) determine a general subordination policy for the non-constraint resources (Schragenheim and Ronen, 1990:18-19,22).

Schragenheim and Ronen also used simulation to examine buffer management as a diagnostic tool for production control. A simulation of buffer management was carried out on the example used in their DBR shop floor control article mentioned above. They conclude that buffer management enables management to focus on the correct actions to keep system performance intact, monitor protection and lead time trade-off, and assess the impact of major changes or improvements implemented (Schragenheim and Ronen, 1991:74, 78-79).

This article provides further support for the merits of TOC/DBR by demonstrating through the use of simulation that the DBR approach is a technique that produces a feasible and close to optimal solution. Thus, this article also lends credibility to Ogden's decision to apply TOC concepts. The article also uses simulation to demonstrate the benefits of buffer management and, as such, could provide insight into what results buffer management might effect in the landing gear division at Ogden.

Applications/Case Studies. Valmont Industries of Brenham, Texas is a producer of steel poles for the construction and utility markets. Glen Reimer, the Materials Manager at Valmont posed the question of whether MRP can coexist with TOC. Using the case study approach, Reimer examines the application of TOC to Valmont Industries' job shop, steel pole fabrication operation. Valmont had grown from a company with manual systems and no accurate means of tracking inventory to accompany with a "Class A" MRP system; however, they found themselves setting priorities according to orders that had the least amount of shortages rather than according to the latest orders. Past-due hours grew, rescheduling became the rule, and large queues appeared in front of every machine. After reading The Goal, by Goldratt and Cox, Valmont's general manager acknowledged that TOC was worth investigating as a way to improve their operation. The issue of whether MRP can coexist with TOC arose out of concern that Valmont would have to discard their existing MRP system, a system in which they had invested considerable time and money, and start over rather than interfacing TOC with MRP (Reimer, 1991:48-49).

The author presents the case in terms of major milestones, to include a brief analysis of the proposed implementation. This analysis surfaces questions concerning TOC applicability to Valmont's operation and compatibility with MRP. The result of the analysis was a green light for implementation of TOC in a job shop fabrication operation under an MRP system. The implementation was carried out with the goal of better use of the existing MRP system in mind (Reimer, 1991:49).

Reimer describes Valmont's application of the drum-buffer-rope (DBR) technique of shop floor control, the development of a system to measure the performance of the subordinate or non-constraint areas, and training conducted to educate and solicit support from those people who would actually make the "nuts and bolts" of the implementation a reality (Reimer, 1991:49-50).

Reimer implies that implementation of TOC at Valmont Industries demonstrates that MRP and TOC can coexist successfully by suggesting that others might like what they see upon interfacing MRP with TOC. He supports this conclusion with the results of implementation. Reducing batch sizes, ignoring setups, and producing only to order resulted in a large reduction in work-in process (WIP) on the shop floor to the extent that WIP was being pulled rather than pushed from machine to machine. Scrap and reject parts dropped from approximately 15% to approximately 2%. Additional time experienced at most workcenters was used to cross-train operators. By producing to order and not to stock, finished goods inventory was depleted. On-time shipments improved and the end of the month rush with its accompanying overtime disappeared. Graphs included in the case showed that earnings based on TOC formulas for throughput and earnings improved considerably after TOC implementation and standard performance measures for inventory turns, meeting due date, and average days delayed showed improvement (Reimer, 1991:51-52).

In light of the condensed form of this case study, Reimer discusses only the key actions and changes enacted in the implementation of TOC. This presents one possible limitation of the study in that there may be some significant steps omitted for the sake of brevity. Another limitation arises from the fact that the author was most likely intimately involved with implementation and may not be presenting the case in a totally unbiased manner. The author himself acknowledges that all aspects of implementation did not go exactly as planned. Mistakes were made and problems were encountered in attaining the level of performance set by the company. This is a limitation in itself, but also leads to the question of whether or not results achieved were actually the result of TOC implementation or other influencing factors. Despite its limitations, this case study was included in the literature review because it presents a real-life application of TOC in a manufacturing environment. The researchers felt that it might serve as a reference point for their case study in terms of how the study was conducted, what key actions and changes were implemented at Valmont Industries, and what the results were.

Giauque and Sawaya's experience assisting several companies design and implement control systems convinced them that there are advantages and disadvantages for all systems (Giauque and Sawaya, 1992:36, 38-39). They present a case study to illustrate how the basic characteristics of MRP, MRP II, JIT, and OPT/TOC can be combined to take advantage of the strengths of each approach. The case study results indicate that no one production control technique is the best. Each has strengths and weaknesses, and each is more appropriate in certain situations. In addition, the case indicates that two or more techniques can be used simultaneously for different purposes or in different parts of an organization. There are also concepts within each technique that can be useful by themselves, such as short setups; the role and management of bottlenecks; concepts of derived demand, lead time offsetting, and coordinated replenishment; the discipline in production planning; bill-of-material maintenance; and inventory-record accuracy (Giauque and Sawaya, 1992:36, 38-39).

Giauque and Sawaya's case study concerns a company which manufactures several million units per year of a product with over twenty variations. Several elements of MRP, JIT, and OPT/TOC were used to create a system that worked well in that particular operating environment. JIT contributed the concept and advantages of close coupling. Lead-time offsetting of matching subassemblies and components came from MRP, as well as overall product planning. The closely coupled system was used for scheduling and production. OPT/TOC insights were instrumental in overall capacity management, setup strategy, and capacity expansion (Giauque and Sawaya, 1992:39).

As a case study of a manufacturing company, this article was included in the review of literature based on its potential to provide general case study guidelines. In addition, the article examines various production control systems, including OPT/TOC. The authors' conclusion that concepts within each technique can be useful by themselves might prove to be useful in understanding how improvements may be made in an organization such as the Landing Gear Division at Ogden, even if not all principles or concepts within a specific technique are implemented as per the "textbook".

Due to the general lack of literature available concerning TOC/DBR implementation validation efforts, the literature reviewed included a behavioral case study of just-in-time (JIT) implementation by Safayeni and Purdy (Safayeni and Purdy, 1991:213-228) to see how another research team studied the implementation of a production management philosophy and validated results. In addition, the article was reviewed to provide support for methods chosen by the researchers, such as semi-structured interviews and summary statistics.

Safayeni and Purdy's case study concerned JIT implementation in the circuit pack area of an electronics firm. The primary focus of the study was to see how workers perceived JIT when implemented in their work area. Eight operators and four supervisors were interviewed. General background information about the JIT implementation in the circuit pack area was collected from the employees during initial meetings. Then, interviews were conducted using a semi-structured interview questionnaire designed for studying the JIT implementation. The purpose of the study was explained to the interviewees in terms of higher management's interest in employee satisfaction. The individuals interviewed were assured of the confidentiality of individual responses. Their open and honest opinions were solicited. It was explained that their responses would be presented to management in aggregate form. Each individual interview took approximately one hour (Safayeni and Purdy, 1991:213-215).

Due to the small sample size, findings were presented with simple summary statistics representing indicators of the pertinent issues. Despite the small sample size, the data exhibited certain informative patterns concerning the JIT situation. The results indicated that there had been many positive improvements since JIT implementation to include the overall positive perception of JIT by participants. There was a perception that communication, cooperation, and level of job involvement had increased. Problems with the JIT situation relating to the environment of the circuit pack area surfaced. Participants perceived that the performance evaluation system was the most significant problem with JIT because it drove production towards a "push" system rather than encouraging JIT. In addition, uncooperativeness of operators was noted by the operators themselves as a problem in the circuit pack area (Safayeni and Purdy, 1991:213-221).

Safayeni and Purdy concluded that JIT manufacturing increases the need to effectively handle environmental problems as well as sub-area problems due to the lower levels of inventory. The reduction of inventory increases the interdependence of organizational activities, thus requiring an efficient and effective problem-handling capacity. Safayeni and Purdy present a discussion concerning the difficulty large functional organizations have with the increased coordination required for effective problem handling. To overcome this limitation, they propose an organizational team approach as a temporary means of dealing with increased interdependencies (Safayeni and Purdy, 1991:221-225).

Summary

The purpose of the review of literature was to gain insight into the background of the case study of the Ogden ALC Landing Gear Division, the environmental factors which prompted action, previous process improvement efforts, TOC/DBR basics, DBR in a remanufacturing environment, AFMC experiences with TOC/DBR, and any previous validation efforts or other related research. Information gained from this review facilitated the development of the methods used to accomplish the present research. The resulting methodology is the subject of the next chapter.

III. Research Methodology

The objective of this research was to validate the nature and extent of success in implementing TOC in the remanufacturing environment at the Ogden ALC Landing Gear Division (OO-ALC/LIL). The research methodology in this chapter establishes the overall plan for achieving this objective by answering the investigative questions.

Investigative Questions

The investigative questions for this research are as follows:

1. What was done to implement TOC at OO-ALC/LIL?

2. How was performance success defined and measured?

3. What was the performance of OO-ALC/LIL before and after TOC implementation?

4. Can the changes in performance be reasonably attributed to TOC implementation?

5. What are the unique characteristics of the remanufacturing which affect TOC implementation success?

Research Design

To answer the five investigative questions, the case study research method was selected for the reasons explained in the Research Methods section which follows. TOC implementation at the Ogden ALC Landing Gear Division was the unit of analysis for this study. The decisions, methods, procedures, and available results of the implementation were documented to validate the nature and extent of success in implementing TOC in the remanufacturing environment at OO-ALC/LIL.

Research Methods

Yin, in his book about case study research, defines a case study as follows:

> A case study is an empirical inquiry that: investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used. (Yin, 1989:23)

This study was exploratory in nature and thus, required an empirical research methodology to investigate TOC implementation within the real-life context of a remanufacturing environment in which the boundaries between TOC implementation and the peculiarities of the remanufacturing environment were not clear. Such multiple sources of evidence as a literature review, written documentation from Ogden, and interviews were used.

Case study designs are categorized into four types by Yin. The first of the four types is the single unit analysis which was selected for this thesis. Yin provides three rationales for selecting the single case design. The first reason to use this design is when the case can confirm, challenge, or extend a well formulated theory. The second is when the case is unique and any occurrence of the phenomenon of interest is worth documenting. The final rationale is when the case is revelatory (Yin, 1989:47-49). For this study the single case design was chosen because the case is designed to reveal what Ogden did to implement TOC, what effect it had, and what unique aspects about the remanufacturing environment affected the TOC effort.

Benbasat and others state that the unit of analysis in a single-case study can be an individual, group, organization, or a specific project (TOC implementation) or decision. They suggest that single-case studies are "most useful at the outset of theory generation and late in theory testing," and "may also be used to test the boundaries of well-formed theory" (Benbasat and others, 1987:373-374). This case study was viewed as being useful at the outset of generating theory concerning TOC implementation within a remanufacturing environment. Yin emphasizes that case studies are used to expand and generalize theories (Yin, 1989:21). This study was used to expand the application of TOC to a remanufacturing situation.

Merriam defines a qualitative case study as "an intensive, holistic description and analysis of a bounded phenomenon such as a program, an institution, a person, a process, or a social unit" (Merriam, 1989:xiv) and explains that a case study is used to gain an in-depth understanding of a situation and its meaning for those involved (Merriam, 1988). This case study was an analysis of the process and results of implementation of TOC in a remanufacturing environment with the goal of validating the nature and extent of success in implementing TOC procedures.

Eisenhardt states that the case study is a research strategy that concentrates on understanding the dynamics present within single settings (Eisenhardt, 1989:534) and can be used to provide description, test theory, or generate theory (Eisenhardt, 1989:535). The case study research strategy in this case concentrated on understanding the unique elements of TOC implementation present in a remanufacturing setting and was used to validate the nature and extent of success in implementing TOC in this setting.

Schendel and Hofer provide an overview of theory building (Schendel and Hofer, 1979:385). Theory building includes the first three stages of theory evolution to include: 1) exploration, 2) concept development, and 3) hypothesis generation. In their conceptual overview table of theory building and theory testing, Schendel and Hofer suggest that the research design appropriate for theory building in the exploration stage is the in-depth case study. Theory building in the next two stages of concept development and hypothesis generation require few to several comparative case studies (Schendel and Hofer, 1979:387). As a single case study, this study was limited to theory building in the exploration stage. The purpose was to explore the territory of TOC implementation in a remanufacturing environment and validate the nature and extent of success and, as such, begin to build theory about the unique aspects of implementing TOC in a remanufacturing environment.

Schendel and Hofer state that in general, there are two types of research. These are descriptive research and normative research. Normative research is used to help develop prescriptive theory or theory that describes what will happen if the "prescription" is followed. The goal of descriptive research is merely to describe what is there and what are the key issues (Schendel and Hofer, 1979:388). The goal of this study was to describe TOC implementation at the Ogden ALC landing gear remanufacturing facility and validate the nature and extent of success. In that context, the researchers make no attempt to generalize their findings across other depot remanufacturing environments.

Quality Considerations

Yin presents four objectives for achieving quality in case study research designs, along with tactics for meeting these objectives and the phase of research in which the objectives should be addressed. These are shown in Table 1.

Table 1. Case Study Tactics for Four Design Tests (Yin,1989:41)

Tests	**Case-study Tactic**	**Phase of Research in Which Tactic Occurs**
Construct validity	use multiple sources of evidence	data collection
	establish chain of evidence	data collection
	have key informants review draft case study report	composition
internal validity	do pattern matching	data analysis
	do explanation-building	data analysis
	do time-series analysis	data analysis
External validity	use replication logic in multiple case studies	research design
Reliability	use case study protocol	data collection
	develop case study database	data collection

To achieve construct validity, multiple sources of evidence were used in the data collection phase of research. These sources included a literature review, written documentation from Ogden, and interviews. In addition, key personnel interviewed at Ogden had the opportunity to review and correct factual errors in the draft case study report during report composition.

Explanation-building establishes a causal relationship, whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationships (Yin, 1989:40-41). Explanation-building was used in this research as the case-study tactic to achieve internal validity during the data analysis phase of research by examining relationships between actions taken to implement TOC at Ogden and resulting improvements. Data analysis is discussed in a separate section in this chapter.

According to Yin, external validity is accomplished when a domain is established to which findings of a study can be generalized (Yin, 1989:40). The case study tactic for this design test occurs during the research design phase and consists of using replication logic in multiple case studies (Yin, 1989:41). This particular quality consideration resulted in a limitation of this study because it is a single case study and as such does not establish even a limited domain (other depot remanufacturing facilities) to which the findings of the study can be generalized. Schendel and Hofer state that a descriptive theory which applies to only a single case study is not a theory, but a random aberration without additional testing to determine whether the theory is an aberration, a limited domain theory, or a universal theory (Schendel and Hofer, 1979:388). This study, however, was designed to address only the first stage of theory building, the exploration stage, for which a single case study is appropriate. It was the belief of the researchers that a single case study to explore the concept of TOC implementation in a remanufacturing environment and validate the nature and extent of success is beneficial in beginning to build theory concerning the unique aspects of implementing TOC in a remanufacturing environment.

Reliability is achieved through use of case study protocol (documentation of the case study methodology) and by developing a case study database during the data collection phase of research. Using case study protocol during data collection (such as semi-structured interviews, historical data collection, and observation with note-taking) ensures that the procedures of a study can be duplicated with the same results (Yin, 1989:4041). This research developed a case study database consisting of multiple sources of evidence gathered using case study methods of data collection to include a literature review, gathering written documentation from Ogden, and interviews. In addition, two investigators were used to enhance confidence in the accuracy of the data (Benbaset and others, 1987:374) and in the findings (Eisenhardt, 1989:538).

Sample Selection

Schendel and Hofer state that the choice of sample size and data-gathering methods will usually reflect the stage of theory evolution. In the exploratory stage of theory building such as this study is concerned with, the choice of data collection methods and typical time and resource constraints, usually mean a small sample size, sometimes as small as n=1 (Schendel and Hofer, 1979:389).

Purposive sampling was used to select Ogden ALC Landing Gear Division as the single unit of analysis in this case study. The population of interest consisted of depot remanufacturing facilities that have applied TOC to a remanufacturing process. Purposive sampling was used to select a sample which could provide the most insight and understanding to the researchers (Merriam, 1988).

The landing gear repair facility at Ogden ALC was selected because TOC implementation was well advanced by the time research was accomplished. Another consideration in the site selection was that full support was available from HQ AFMC/LGP TOC facilitator and the management of OO-ALC/LIL, Landing Gear Repair Division.

Data Collection

Data collection consisted of reviewing literature, gathering written documentation, and conducting interviews. Eighteen personnel assigned to the OO-ALC/LIL division who actively participated in the TOC implementation process were interviewed. The organizational level of personnel interviewed ranged from directorate level to shop floor personnel, to include division, branch, and first-line supervision. Thirty-minute to one-hour interviews were conducted face-to-face during a three-day site visit. Seventeen interviews were recorded and transcribed for data accuracy. Written notes were taken during one interview because permission to record the interview was not granted. An interview instrument was used for the interviews to ensure that similar data was collected from all personnel. A copy of the interview instrument used to conduct the interviews is provided in Appendix A.

Data to answer investigative question #1 (IQ #1) concerning what was done to implement DBR at OO-ALC/LIL was obtained from written documentation and interviews. Written documentation from Ogden included: minutes of meetings, correspondence, lists of task group/team members and other key TOC implementation players, and organizational charts.

During the interviews, respondents were asked a series of questions designed to find out what actions or steps were taken to implement TOC in the landing gear division.

To determine how performance success was to be defined and measured (IQ#2), written documentation was gathered from Ogden and from published works by Goldratt and other TOC experts. Written documentation included: literature about traditional throughput, inventory, and operating expense (T, I, and OE) measures; documentation stating OO-ALC/LIL's operationalized measures of T and I; and available copies of reports in T and I format.

The division made no attempt to operationalize OE, assuming (according to a key PAT team member) that since labor and plant equipment would remain constant because no funds were authorized to be expended, operating expenses would not change. Throughput was operationalized as wheels "sold" to supply and inventory was operationalized as wheels in process (WIP) by OO-ALC/LIL.

In addition, information was collected from interview respondents to determine their assessments of the indicators management was using to judge successful performance and their ideas about other indicators which might be helpful in evaluating performance.

Written documentation from the Technology and Industrial Support Directorate (OO-ALC/TIE), the production scheduling section (OO-ALC/LILPS), the end item managers (OO-ALC/LILA), resource management personnel (DAO-DE Hill/FCM) and OO-ALC/LICD provided the data to answer IQ #3 dealing with the performance of OO-ALC/LIL before and after TOC implementation. This documentation included wheel flowdays data from OO-ALC/TIE flowdays analyses conducted prior to implementation and from informal production scheduling (OO-ALC/LILPS) wheel flowdays reports containing after implementation data. The researchers operationalized inventory as flowdays due to the unavailability of work in process (WIP) data. WIP worksheets were used on a daily basis as a management tool, but were not retained on file anywhere in the division. Flowdays represent the time wheels spend in the repair process, thus wheels in process are a function of flowdays. In addition, wheels negotiated and wheels "sold" data from OO-ALC/LILA negotiation worksheets were collected for the four quarters before TOC implementation began and the four quarters following implementation completion.

Finally, revenue and expense figures were collected from DAO-DE Hill/FCM. Despite the landing gear division's decision to ignore OE, the researchers felt that to truly validate the nature and extent of TOC implementation success, some measure of OE should be examined. Unfortunately, these data were in aggregate form and all attempts to disaggregate the information were unsuccessful. Likewise, attempts to gather overtime data by product line were unsuccessful.

To ascertain whether the changes in performance can be reasonably attributed to TOC implementation (IQ #4), data was collected from published works by Goldratt and other TOC experts concerning traditional TOC results. In addition, the before and after performance data collected for IQ #3 was examined for this question.

Interview respondents were asked if they attributed changes in performance to TOC and were also asked about other programs, projects, or organizational changes that may have contributed to or influenced changes in performance.

Data to answer IQ #5 concerning the unique characteristics of the remanufacturing environment which affect TOC implementation success was collected from literature, as well as from interview respondents. Written documentation gathered consisted of literature on AF remanufacturing applications. Interview respondents were asked about the challenges/problems caused by disassembly, the probabilistic nature of repair, and the variability of the supply system; three areas identified in the literature as unique to remanufacturing.

Data Analysis

Analysis consisted of within-case analysis which typically involves a detailed case study write-up which is often pure description, but is key to generating insight according to Pettigrew and Gersick as cited by Eisenhardt (Eisenhardt, 1989:540). In addition, Eisenhardt notes that the goal of a detailed case study write-up is to become intimately familiar with a case as a stand-alone entity. A detailed case study write-up is presented in Chapter IV. Data analysis specific to each research question is discussed separately in subsequent paragraphs.

Investigative Question #1. For the first investigative question, the primary data examined were the interview responses. The written documentation was used primarily as a means to cross check the accuracy of events as revealed by the interview responses. To determine how TOC was implemented at OO-ALC/LIL, respondents were asked what types of TOC training they received; if teams were formed, and if so, what type; how the project was promoted and to whom; why there was a need to use TOC concepts in the division; and why the wheel repair process was selected to be improved. They were also asked what methods were used to identify the constraint; what was identified as the constraint; what was done to exploit the constraint; what was done to subordinate other resources to the constraint; what actions were taken to elevate constraint capacity; what methods were used to place and size inventory buffers; what methods were used to control the flow of reparable wheels inducted into the repair process; and what actions were taken to continue the improvement process. The responses to these questions were summarized in one of the following ways: by number of individuals who responded with a particular answer, percentage of total respondents who responded with a particular answer, or by response and number of times mentioned. Appendix B contains response summaries for the interview questions.

Based on the interview responses and on data from the written documentation, the actions taken to implement TOC in the landing gear division were summarized and presented using a step by step narrative organized by the five focusing steps of TOC.

Investigative Question #2. For the second investigative question, Ogden's operationalized measures of throughput and inventory were examined, as well as interview responses. Respondents were asked whether or not they felt that wheels "sold", wheels in process, and wheel flowdays were accurate measures of performance. They were also asked if there were any other indicators which they felt were more accurate measures of success. Responses were summarized by response and number of times mentioned. In addition, available revenue and expense data were examined, and found to be unusable for the reasons mentioned in the Data Collection section.

Based on OO-ALC/LIL's operationalized measures of T and I and the summary of interview responses, the researchers developed operationalized measures of T and I to use in comparing before and after TOC performance for the purpose of validating the nature and extent of success in implementing TOC in the OO-ALC/LIL remanufacturing environment. It was the desire of the researchers to also operationalize OE in terms of overhead and general/administrative expenses for wheels or overtime, but as mentioned previously, this was not possible.

Investigative Question #3. T and I performance data before and after TOC implementation (IQ#3) were analyzed using simple summary statistics as Safayeni and Purdy (1991) did in their validation of a JIT implementation and presented in the form of summary tables and graphs. In addition, the researchers followed Miles and Huberman's recommendation for the use of displays, such as tables, for highlighting similarities and differences (before and after data) and allowing for a more refined data analysis (Miles and Huberman, 1984:16).

Investigative Question #4. For the fourth investigative question, traditional literature about TOC and its expected results was examined, along with the before and after performance data from IQ #2.

Interview respondents were asked if the changes in performance can be reasonably attributed to TOC implementation. They were also asked what other programs, projects, or organizational changes may have contributed to or influenced performance changes. The responses to these questions were summarized by response and number of times mentioned.

Based on the summary of responses, and on the examination of traditional TOC results and the landing gear division's before and after performance data; the researchers examined relationships between TOC and resulting performance changes.

Investigative Question #5. Finally, for the fifth investigative question, literature concerning the application of TOC in a remanufacturing environment was examined and interview respondents were asked questions about the areas identified in the literature as unique to remanufacturing.

Respondents were asked what problems or challenges were caused by the need for disassembly prior to repair, what problems or challenges were caused by the probabilistic nature of the repair process, and what problems or challenges were caused by the variability of the supply system. The responses to these questions were summarized by frequency of response to arrive at conclusions concerning the importance of each unique characteristic and how each might have affected implementation success in terms of applying the five focusing steps of TOC.

Summary

This chapter established the overall plan for answering the five investigative questions. The plan unfolded through a discussion of research design, research methods, quality considerations, sample selection, data collection, and data analysis. Chapter IV is the case write-up which begins to answer the investigative questions. The remainder of the investigative questions are answered in Chapter V.

IV. Case Study

This chapter provides a description of the events that occurred in the implementation of Theory of Constraints principles in the Ogden ALC Landing Gear Division (OO- ALC/LIL). In doing so, the answers to four of the five investigative questions will be addressed in whole or part. Specifically, complete responses to investigative question number one, "What was done to implement TOC at OO-ALC/LIL?", and investigative question number two, "How was performance success defined and measured?", are found in this chapter. A partial response to investigative question number three addresses in general, "What was the performance of OO- ALC/LIL before and after TOC implementation?" The specifics of the performance before and the performance after are covered in Chapter V. Finally, this chapter will provide the case-specific aspects of investigative question number five, "What are the characteristics of the remanufacturing environment which affect TOC implementation success?", with additional discussion of the remanufacturing environment in Chapter V.

OO-ALC/LIL Organizational Structure

The Ogden ALC Landing Gear Division is one of five divisions in the Commodities Directorate (OO-ALC/LI) located at Hill AFB, UT. In addition to landing gear, the Commodities Directorate provides management of and depot level repair for weapons related materiel such as munitions, missiles, trainer systems, photographic/reconnaissance equipment, instruments, and pneumatic/hydraulic equipment. OO-ALC/LIL manages and repairs landing gear for the U. S. Air Force in an industrial complex located in buildings #505 and #507 on the southeast side of the base. The three primary units in OO-ALC/LIL are the Customer Support Unit (LILA), the Engineering Unit (LILE), and the Production Unit (LILP). Figure 1 shows the organizational structure of the Landing Gear Division. The Production Unit performs the repair of the landing gear components, which consist of the struts, brakes, and wheels. The focus of this case study was on the Production Unit and the wheels that are repaired there.

Competition: The Motivation for Change

As noted in Chapter II, the Air Force Materiel Command is actively participating in the program to compete depot workloads with private industry. One of the depot workloads scheduled for competitive bidding in the Command's program was aircraft wheels. This competition of the wheel workloads became a key motivating factor for depot management to take a critical look at the processes within the Production Unit at the Ogden ALC Landing Gear Division. When asked why the wheel repair process was selected to be improved, 14 of 18 interviewees stated that the impending wheel repair workload competitive bid was the reason. Appendix B lists the interview questions as read to the interviewees, and provides a summarization of interview responses. Any response numbers referenced in this chapter and the next chapter can be found in the summarization.

Scope and Nature of Wheel Repair Workload

Wheel repair requirements are negotiated quarterly between two units within the Landing Gear Division, the Customer Support Unit (OO-ALC/LILA) and the Production Unit (OO-ALC/LILP). This negotiation is broken out by the nose and main wheels of each weapon system and is based on the projected demand

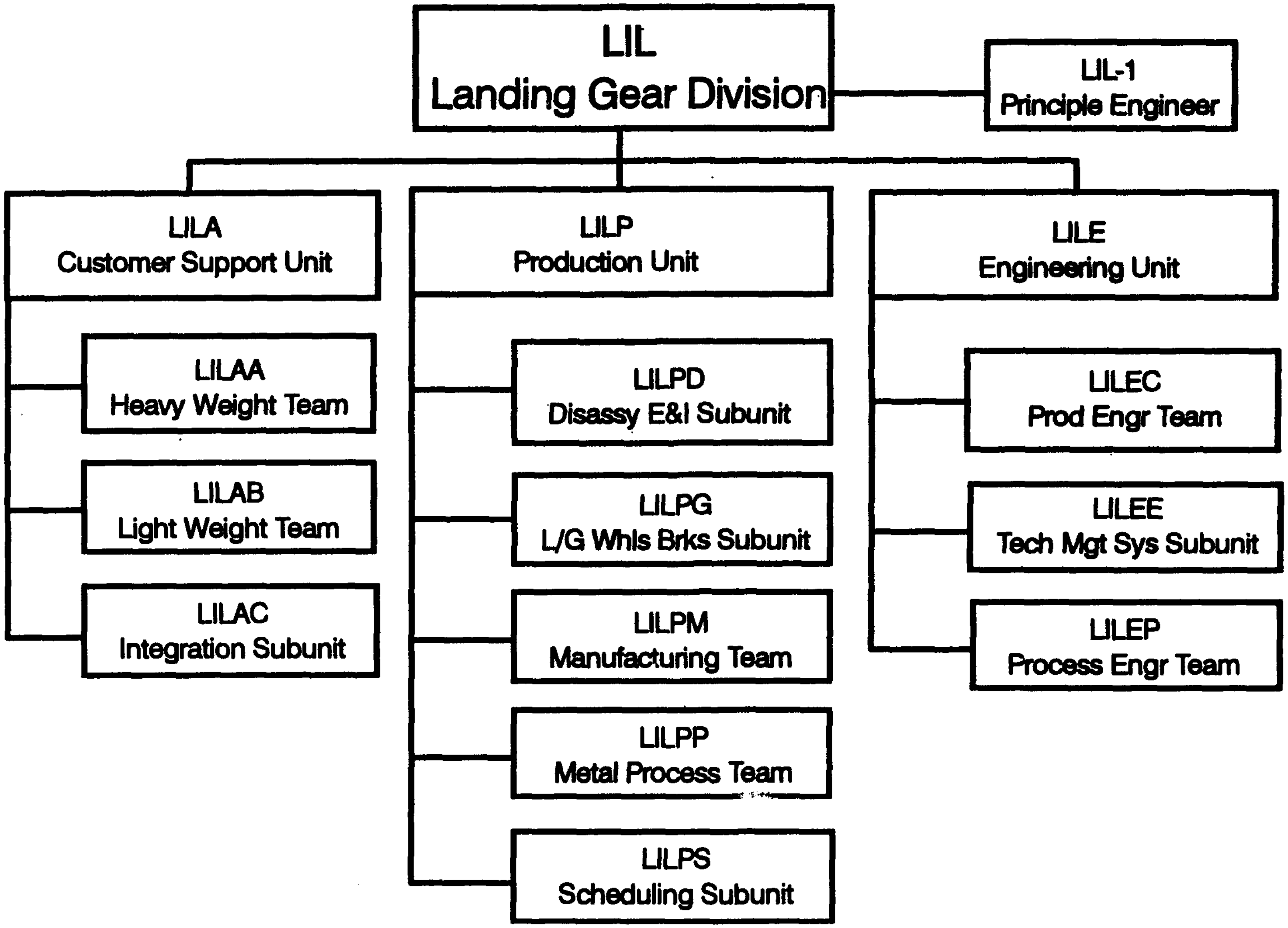


Figure 1. Landing Gear Division Organizational Structure

for wheels by the operational bases and other depots, funding levels for the repair process, and the repair capability of the Production Unit. Table 2 shows the weapon systems and wheel NSNs that are supported by the Landing Gear Division. The demand for wheels is a function of failure rates and time change intervals. Once the negotiated quarterly requirement has been established, that quantity of wheels by weapon system type becomes the Production Unit's target of output to be achieved by the end of the quarter. This single, quarterly, target output allows for flexibility in scheduling wheels into the repair process on a daily basis. The daily schedules are a function of the availability of wheel types in reparable supply, repair parts from supply, and the work load balance of different types of wheels that can flow through the repair process.

The Production Unit can "re-negotiate" a portion of the quarterly requirement if the unit finds that it will be unable to produce the target output by the end of the quarter. This situation of missed target output may result from circumstances such as 1) reparable wheels not returning to the depot as projected, 2) failure to obtain required types and quantities of repair parts when needed, 3) poor scheduling of wheel types throughout the quarter, or 4) backlogs of wheels in the repair process. When renegotiation occurs, repair funds are reallocated and unmet requirements may be moved to the following quarter's requirement depending on updated projections of wheel demands by the inventory management process.

Problems with Wheel Repair

Before the initiation of an improvement project for the wheel repair process, there were management indicators and other activities that showed signs of internal production difficulties.

Table 2. Wheels Repaired by Weapon System and NSN

Weapon System	Wheel Type	National Stock Number	Weapon System	Wheel Type	National Stock Number
A10	MAIN	16300012257451	F100	NOSE	1630000874924
A10	NOSE	1630005969637	F106	MAIN	1630007828521
A7	MAIN	1630010159879	F106	NOSE	1630008963570
A7	MAIN	1630011392892	F111	MAIN	1630001576723
A7	NOSE	1630000752003	F111	MAIN	1630008329087
B1B	MAIN	1630011829879	F111	NOSE	1630009414191
B1B	NOSE	1630011659072	F111	NOSE	1630008430965
B52	MAIN	1630000542557	F15	MAIN	1630011375742
B52	MAIN	1630009009739	F15	MAIN	1630010585912
B52	MAIN	1630002420942	F15	MAIN	1630011414695
B52	MAIN	1630012286043	F15	MAIN	1630012251893
C130	MAIN	1630009658700	F15	NOSE	1630010716112
C130	MAIN	1630010385126	F16	MAIN	1630013201448
C130	NOSE	1630005166737LC	F16	MAIN	1630013173318
C130	NOSE	1630009141329	F16	MAIN	1630012523593
C130	NOSE	1630008961212LC	F16	MAIN	1630010389239
C130	NOSE	1630009141328	F4	MAIN	1630004463778
C130	NOSE	1630010140656LC	F4	NOSE	1630007300126
C141	MAIN	1630011326400	F4	NOSE	1630008521432
C141	MAIN	1630011253957	F5	MAIN	1630001398476
C141	MAIN	1630010506139	F5	MAIN	1630010416012
C141	MAIN	1630004534893	F5	NOSE	1630010555056
C141	NOSE	1630000816687	KC135	MAIN	1630000139129
C5	MAIN	1630011826267	KC135	MAIN	1630004927144
C5	NOSE	1630002861879	KC135	NOSE	1630004210319
E3A	MAIN	1630010098474	KC135	NOSE	1630012947958
E3A	NOSE	1630010109337	KC135	NOSE	1630008873207
F100	MAIN	1630009000725	T33	MAIN	1630004063998XW

Flowdays. Wheel flowdays was defined as the number of days the wheel spends in the repair process from the time of induction into the disassembly operation until the end of the assembly operation, and is measured by the entries on AFLC Form 958, Work Control Document. The aggregate average flowdays of all wheel types was considered high at 40 days. The long flowday times resulted in the need to expedite Mission Capable (MICAP) requirements for wheels through the repair process to meet urgent demands. The long flowday times also caused an increase in computed quantities of wheel inventory requirements to fill the depot repair pipeline, tying up funds and wheel inventory that could be used elsewhere in the logistics system. Thus, wheel flowdays are directly related to the amount of wheel inventory in the depot repair cycle, also known as work in process, or WIP.

Work in Process. Typically, the WIP count ranged from 1800 to 2000 wheels in building #507. The high WIP count took up floor space, causing congestion and requiring workers to hunt through piles of wheels when a particular type of wheel was needed.

Materiel Supportability. An OO-ALC/LIL Materiel Supportability Study indicated that management was aware of the problems related to parts shortages in the repair process and was actively seeking solutions. The study showed that as of the end of 31 Mar 1991, there were 67 materiel supportability problems in the wheel repair process. Of these 67 problems, 55% were caused by errors in the bill of materials and 37% were due to unforecasted parts requirements (LIL Materiel Supportability, 199:147). A separate management briefing of the same supportability status as of 17 July 1991 showed that the number of problems had risen to 90 for the wheel repair process. Bill of material errors and unforecasted requirements accounted for 41% and 39% of the cause, respectively, and delinquent contracts were 16% of the problem (LI Management Indicators, 1991). The parts supportability problem is a factor in high WIP counts and longer flowdays when wheels are inducted into repair without adequate parts, and can cause production to fall short of the negotiated requirement.

Percent of Requirements Produced. A management briefing in the third quarter of 1991 showed that OO-ALC/LI was using a measure of "MISTR (Management of Items Subject to Repair) Exchangeable Repair Workload" as a management indicator of success in meeting customer requirements. The measure was percent produced as calculated from the ratio of actual production to negotiated output requirements. The goal was 100%, but quarterly measures did not consistently meet that goal. For all the units produced by OO-ALC/LI (of which wheels was a portion), the first and second quarters of FY91 had percents produced of 89.7% and 91.8%, respectively (LI Management Indicators, 1991). The percent produced for wheels in the first, second, and third quarters of 1991 were 93.4%, 102.3%, and 91.1%, respectively.

Attraction to the Theory of Constraints

The Landing Gear Division chief received formal training in the Theory of Constraints in late 1990 and was interested in conducting a pilot program within his organization. An industrial engineer in the Technical Support Branch (OO-ALC/LICT) read The Goal (Goldratt and Cox, 1992) and was also interested in testing the TOC principles. The idea surfaced between them to undertake a process improvement project and the wheel repair process was seen as a good candidate process. The wheel repair process was chosen because it 1) was scheduled for competitive bid (14 of 18 responses), 2) was viewed as a relatively simple process for a TOC pilot program (8 of 18 responses), and 3) was viewed as a process in need of improvement due to visible stacks of WIP (3 of 18 responses).

Beginning the Wheel Repair Improvement Process

Teams. In April 1991, the division chief directed that a Process Action Team (PAT) be formed to evaluate and improve the wheel repair process using the concepts of the Theory of Constraints. The lead industrial engineer was assigned to chair the team and key area workers in the wheel repair process were selected as members. The Total Quality Management (TQM) principle of empowerment was endorsed by management for the team to identify and implement their improvement ideas. The PAT met weekly and reported to the division management steering group as needed. Other workcenter teams were formed to address the issues related to their workcenters. Interview responses provided a 100% confirmation of the use of teams to conduct the process improvement project.

Promotion. The division chief briefed the organization's personnel on the current conditions of the Production Unit and the need for change. Although the process improvement effort was widely promoted within the division, there was no fanfare outside the division. When asked how the improvement project was promoted and to whom it was promoted, 15 Of 18 interview respondents said that division management gave visibility to the project through briefings and it was promoted within the division to all levels of the workforce.

Training. Except for the division chief, the PAT members had no formal training in Theory of Constraints. Several of the members had read some of the Goldratt books and they shared that knowledge with the other team members. In addition, the division chief spent a few days giving the team a brief introduction to the TOC concepts. Formal on-site training in TOC was provided to the team by the HQ AFMC TOC facilitator later in the course of the improvement project. When asked what types of training were received by the interviewees, 11 of 18 responded with having had some type of formal training on TOC after the improvement project began.

Attitudes. The initial efforts of the PAT members met with resistance within the team and among shop personnel. Many shop personnel were content with the way the repair process was being performed and were resistant to change. This negative attitude became an impediment to implementing change and thus, the team's progress and effectiveness were significantly hindered. To overcome this inertia, management had to show strong support for their willingness to adopt change. Therefore, it was necessary for them to direct that some of the team's initial process changes be implemented. The positive results realized from those initial changes became a motivating factor for the team and shop personnel. Thus, a better attitude towards change developed.

The Wheel Repair Process Description

For the reader to appreciate the nature of the process changes made by the PAT that will be discussed later in this chapter, a brief description of each step of the wheel repair process is provided below. The process is described as it was operating before the implementation of the PAT's recommended changes.

The wheel repair process is a multi-step operation by which wheels are returned to serviceable condition. Most of the refurbishing steps use common resource work centers (for example, machining) that also are part of the repair process for brakes and struts. Due to the particular nature of each of the different components (wheels, brakes, struts) and the required refurbishing actions, there are cases where areas or machines are dedicated to only one component. Figure 2 is a logical flow diagram of the wheel repair process. The following is a description of the wheel repair process:

Induction. Reparable wheels received at Hill AFB are stored in the reparable supply warehouse until they are ready for scheduling into the repair process. Wheels enter the repair process in an area of building #507 referred to as the "east wall" where disassembly is performed.

Disassembly. Disassembly is a manual process that consists of unbolting the wheels into inner and outer wheel halves and removing all attached parts, such as bearing races and brake shield linings. From this point, the wheels are handled and processed as separate halves until they are bolted together at final assembly. Any further reference to "wheels" in this process description will have the connotation of "wheel halves". Following disassembly, wheels are then hung on an overhead conveyer rack for transportation to chemical cleaning.

Chemical Cleaning. Chemical cleaning is a process of soaking the wheels in a bath of solvents for the purpose of removing grease and debris, and loosening paint. The conveyer lowers wheels into the bath and the wheels slowly proceed down long tanks of solvents until approximately two hours have elapsed. There are two separate cleaning lines for steel and aluminum wheels.

Blast Cleaning. After chemical cleaning, the wheels must go through a manual blast cleaning process to completely remove all paint.

Anodize Strip. From blasting, the wheels are processed through another chemical bath to strip anodized aluminum from the surfaces that had received previous plating processes.

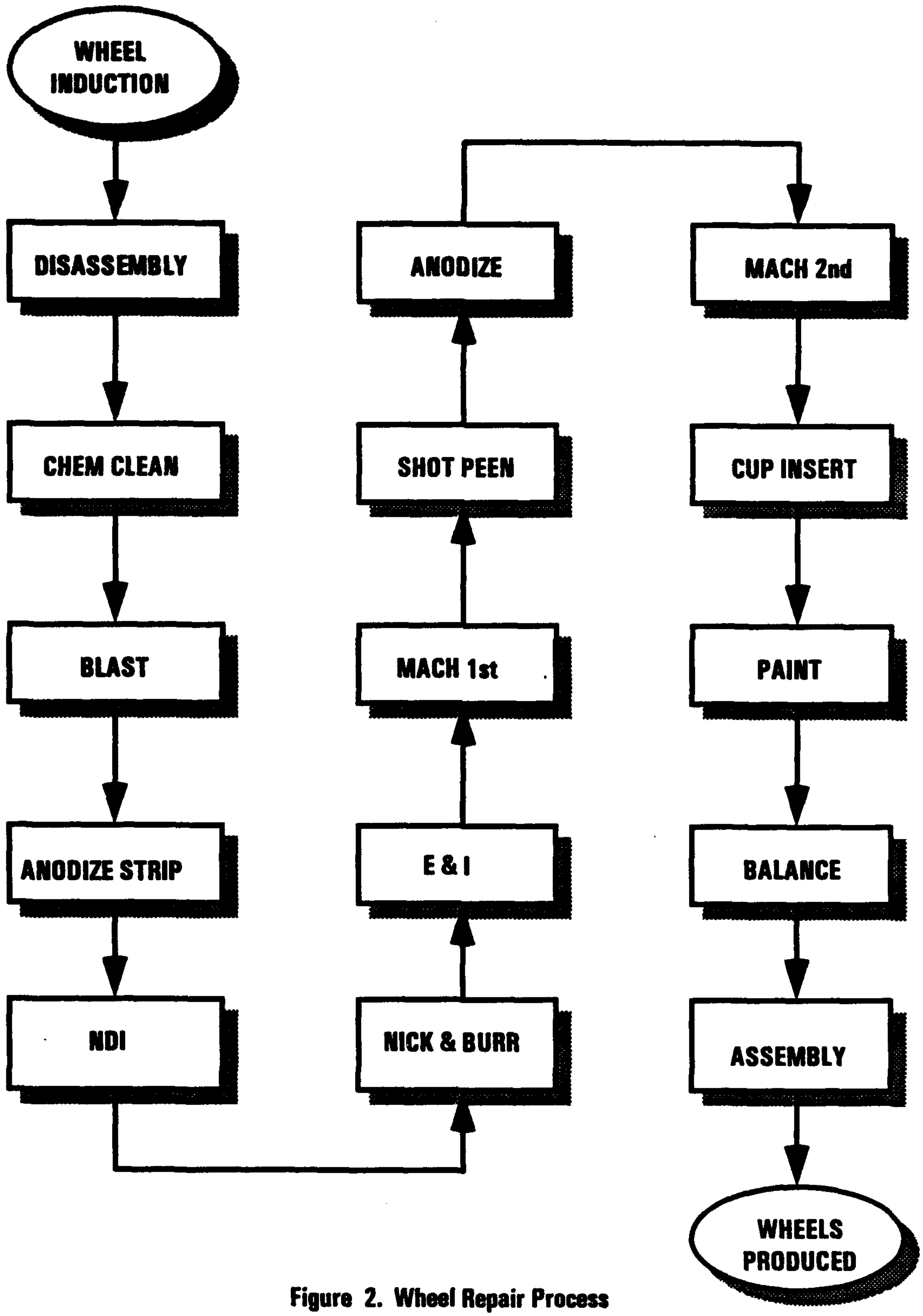


Figure 2. Wheel Repair Process

Nondestructive Inspection. NDI consists of three procedures to detect cracks, flaws, or other defects in the wheels that would cause them to be operationally unsafe and/or uneconomical to repair. The three procedures are fluorescent penitrant inspection, eddy current inspection, and conductivity inspection. All wheels receive one or more of these procedures to determine whether the wheels may continue through the repair process. Defective wheels are condemned at this point and scrapped. The condemnation rate for inner and outer wheel halves can be significantly different. This difference in condemnation causes unmatched quantities of inner and outer wheel halves in the repair process.

Nick and Burr Removal. The next step in the repair process is termed "nick and burr" removal. This process is a manual grinding of the outer rim and other wheel surfaces to remove and smooth minor surface irregularities. These irregularities typically occur during the mounting and dismounting of tires and from normal wear and tear.

Evaluation and Inspection. A critical process in the repair of the wheels is Evaluation and Inspection (E & I) where each wheal half is tagged with a specific machining and plating refurbishment process to return the wheel to technical order specifications. This operation is a primary manifestation of the probabilistic repair environment. Wheels can vary greatly in the extent of damage and the need for different repair operations. Occurrence factors for the frequency of repair operations are based on the decisions made in E & I and the factors play a significant role in the management of the repair process (e.g., setting manpower standards and determining parts requirements). In unique situations, engineering or technical expertise is called upon to support the E & I function in determining specific repair procedures on wheels of questionable reparability.

Thus, wheels may be delayed in the repair process to evaluate the required extent of repair and, in some cases, to develop technical order repair procedures.

Machining. The machining procedures are often the most labor intensive and lengthy of the refurbishment activities in the wheel repair process. Each wheel may require a number of machining actions, such as grinding, milling, boring, shaping, or turning, to resurface holes, key ways, and bearing/bushing bores to required tolerances. Most wheels take a two-step pass through the machining process, with shot peen and plating occurring in between. The machine shop has numerous manually operated and some numerically controlled machines.

Shot Peen. The shot peen operation is required to prepare the wheel surfaces for the anodize plating process.

Anodize Plating. Anodize plating is performed in building #505 and employs the use of racks and conveyers similar to the chemical cleaning process. The plating procedure adds aluminum oxide metal to the wheels and provides a seal for corrosion protection.

Bearing Cup Installation. The start of the assembly process begins with the installation of new bearing cups and it is at this point in the process where wheel halves are mated into matched pairs in preparation for final assembly. Wheels are run through a heat treating machine that brings their temperature to over 200 degrees and expands the bearing bore. New bearing cups are immersed in liquid nitrogen that significantly drops their temperature and contracts the dimensions of the cup. The bearing cups are placed into the bore and the result is a tight fit once the wheel reaches room temperature.

Paint Line. Wheels are then placed on racks suspended from a conveyer line and given two coats of paint. The extent of application of masking tape varies by wheel type. The first coat is primer paint and the second is a finish coat. One hour of drying time is required between each coat. The size of the wheels of different aircraft types (e.g.; B-52 main vs. F-16 nose) is a significant factor in the time to paint each wheel and the space available on the conveyer line to allow for sufficient drying time.

Balancing. The wheels are taken from the overhead conveyer when dry and placed on a roller conveyer to be staged for the wheel balancing process. After wheel balancing has been accomplished, parts kits are placed with the wheels and they are moved down the roller conveyer to final assembly.

Final Assembly. In final assembly, the wheel halves are bolted together and all the required keys, bolts, brake shields, and other parts are attached to the wheels. Any needed paint touch-up is also accomplished at this time. The assembled wheels are moved down the roller conveyer to receive final inspection and the necessary documents. A point is crossed on the conveyer at which they leave the repair process, are counted as produced ("sold to supply"), and become the inventory of the depot supply operation.

Preface to Process Changes

The wheel PAT met regularly over a nine month period to analyze, evaluate, recommend, and implement changes to the wheel repair process. The majority of the process changes were implemented by January 1992. The PAT continued beyond that time to refine and improve upon their previous efforts. The balance of this chapter presents the most noteworthy changes made to the wheel repair process in the Landing Gear Division at Hill AFB, UT. The information about the majority of the process changes is presented in terms of the five focusing steps of the Theory of Constraints as relayed to the researchers from interviews and documentation.

Initial Repair Process Changes

Mating Wheel Halves. Early in the improvement process, the PAT recognized that output was measured in whole wheels, that is, two mated inner and outer wheel halves. However, wheel halves were being repaired independently until they reached the bearing installation operation when they would be mated for final assembly. Since condemnation is applied to each wheel half independently (as opposed to condemning a pair), much of the WIP was composed of excess wheel halves waiting for mates. A new wheel handling policy was implemented stating that only whole wheels, and wheel halves designated to mate with unmated halves that were created by condemnation, would be forwarded from the disassembly operation. Disassembly would return excess unmated wheel halves back to reparable supply. E & I was tasked to mate all wheel halves for processing as whole wheels through the rest of the repair operations.

Parts Supportable Wheels. A second policy change addressed the problem of mated wheels being delayed in the repair process for lack of parts for assembly. The induction of wheels that were not parts supportable into the repair process was a significant contributor to the high amount of WIP. Ten of 18 interviewees noted that the timely availability of the correct types and quantities of parts was the number one problem in the repair of aircraft wheels. Since the problem of parts supportability was external to the Production Unit and beyond the PAT's ability to resolve, an internal OO-ALC/LILP processing policy was established. The policy stipulated that no wheels would be inducted into the repair process without being parts supportable. The definition of a wheel being parts supportable was that the parts for assembly were on base. A later refinement to the policy was that parts would be "kitted" (all required parts per wheel consolidated in bags) prior to the wheels being released to disassembly to ensure that final assembly could occur without an awaiting-parts delay.

Getting Control of WIP. The PAT combined the effects of the above two actions with stopping wheel induction (except for MICAP wheels) for a brief period of time to work off the internal backlog of excess wheel WIP. This action brought the daily average WIP count in the repair cycle from the 1800-2000 range to a low of 380 total wheels. Induction was then restarted, following the new mating and parts policies.

Identification of the Constraint

The search by the PAT members for the system constraint in the wheel repair process took a two-pronged approach. One approach was intuitive and the other was analytical. The intuitive approach focused on identifying where in the system the greatest amount of WIP was accumulating. The team found that the greatest amount of WIP was in front of the machine shop. The analytical approach was supported by the industrial engineers in the Technical Support Office (OO-ALC/TIE). They accomplished a study of each resource's process cycle times to identify and evaluate potential system bottlenecks. Compounding the complexity of the study effort was the consideration of probabilistic repair and the occurrence factors of repair operations for each type of weapon system wheel. This analysis also pointed to the machine shop.

Shaper. In particular, the shaper machine in the machine shop was identified as the system constraint. When asked which resource was identified as the system constraint, 16 of 18 persons interviewed said the machine shop was the constraint and 8 of the 16 further made mention of the shaper as the particular piece of equipment causing the machine shop bottleneck. The function of the shaper is to machine key-way channels on the inner rim of the wheels where the brake assembly is mounted. Different types of weapon system wheels place varying demands on the shaper, with F-16 wheels causing the heaviest workload.

Paint Line. The second operation in the wheel repair process identified by the PAT as a constraint was the paint line. However, the paint line became noticeable as a constraint only after the machine shop constraint had been elevated and wheel output from the machine shop began accumulating as WIP in front of the paint line. The paint line was identified as the second constraint after the machine shop by 13 of 18 interviewees.

Exploitation of the Constraint

Exploiting the Shaper. With the PAT working together with the machine shop quality team, several actions were taken to exploit the shaper. The first action was to improve the daily utilization of the shaper by minimizing machine idle time and by keeping work flowing across it on a continuous basis. Second, tooling setup times were reviewed and procedures redesigned to minimize the time required to change from the processing of one wheel type to another. Finally, a temporary addition of second and third shifts for two quarters was implemented to work off the backlog of WIP that had built up in front of the machine shop.

Exploiting the Paint Line. To exploit the paint line, new racks were fabricated for hanging wheels on the conveyer. These modified racks increased the capacity of wheels on the conveyer and allowed for the appropriate amount of drying time, while still ensuring the required flow of wheels across the paint line. No additional paint stations were added.

Other Exploiting Actions. In addition to focusing on the shaper, the PAT looked for other ways to better utilize the machine shop. One process change reduced the workload in the machine shop by moving the helicoil and bushing removal procedure to the disassembly line.

Another improvement action reduced wheel handling and back-tracking flow by designing a new machine shop layout. This new layout moved non-wheel machines out of the wheel processing area, and grouped the remaining machines into first-run and second-run work cells. The accomplishment of the machine shop layout was apparently the most memorable of the exploitation actions taken by the PAT, since 14 of 18 interviewees identified the layout as one way they exploited the constraint.

The concept of exploitation was also applied to resource areas outside the machine shop. One way to exploit a resource is to eliminate the adding of value to an item that will end up as scrap later in the process flow. One of the probabilistic attributes of the repair environment is the condemnation of wheels that are unsuitable for refurbishment. The PAT accomplished a reduction in unnecessary work by moving portable eddy current inspection equipment from NDI to the disassembly process. For C141 wheels, which have particularly high condemnation rates, this action saved time and materials in disassembly, cleaning, and blasting.

After the PAT implemented the actions to exploit the shaper, the paint line, and other resources in the repair process, it became evident that there was no internal system constraint. The only constraint limiting production was the quarterly demand for wheels. (In TOC parlance, this is a market constraint.) However, the shaper and the paint line could become capacity constrained resources if the proper mix of wheel types were not scheduled to flow across those resources.

Subordination of Other Resources

Subordination of the wheel repair process resources to the system's true constraint, the demand for wheels, took the form of developing and implementing a detailed daily master schedule. Scheduling was accomplished with the objective of meeting the daily requirement of wheels produced, or "sold to supply", without overloading the capacity constrained resources, the shaper and the paint line.

The analytical study that identified the resource cycle times by type of wheel was used to establish a scheduling procedure for managing the capacity constrained resources. Based on this study, different lot sizes of wheel types could be determined that would 1) meet the daily objective of number of wheels produced and 2) schedule a balance of wheel types that had high and low constraint usage, while not exceeding the overall capacities of the constrained resources.

Thus, a scheduling procedure was implemented to induct and process "daily buckets", or measured mixes of whole wheel types that 1) were parts supportable, 2) met the daily demand schedule, and 3) did not exceed the capacities of the constrained resources. Each resource work center adhered to the schedule and each center's daily output became the next center's input for the following day.

Managing the Schedule by the WIP. A manually annotated daily reporting form titled "Daily Wheel Status/Inventory" was established to monitor the wheel WIP counts at several points in the repair process and ensure that the scheduling plan was being properly executed. The form was annotated with the total WIP in the repair process, termed "on work order" and individual WIP counts at the "east wall", first and final run machine shop, plating, and assembly. Printed on the form was a range of high and low WIP counts that served as control limits for each area and helped to indicate where corrective scheduling action was needed when the limits were exceeded. A count of wheels produced at final assembly was also tracked on this form.

Elevation Actions

Since exploitation actions were sufficient to keep the shaper and paint line from continuing as constraints, there was no need to increase their capacities. Consequently, no elevation actions were taken by the PAT.

Efforts for Continuous Improvement

The Landing Gear Division pursued an ongoing series of efforts to manage and improve the wheel repair process and other product lines using the TOC principles. Meetings of the wheel PAT were held regularly to evaluate performance and analyze flow processes (7 of 18 responses). To assist in the evaluations, daily wheel WIP counts and number of wheels produced were tracked against established goals. New TOC efforts were planned for the brake and strut repair processes (5 of 18 responses).

OO-ALC/LIL Established Performance Measures and Goals

The PAT identified measures of the wheel repair process that corresponded to the TOC measures of throughput (T) and inventory (I). These measures were not expressed in terms of dollars as defined by TOC.

Throughput. Throughput was defined by the PAT as wheels produced, or "sold to supply". Initially, a daily target of 50 wheels produced per day was set. This target was derived by dividing the typical quarterly wheel requirement of 3000 wheels by an average of 60 work days per quarter (3000/60 = 50). This target was later revised downward to 40 wheels per day to conform to the drop in average quarterly negotiated requirements.

Inventory. Inventory was measured in two separate, but related ways. The first measure was wheel flowdays. The initial goal for average aggregate flowdays for all wheel types was a reduction from 40 to 20 days. The target was later revised to 10 days. The second measure of inventory was wheel WIP. An initial goal of 500 wheels in process at any given time was set (a reduction from 1800-2000). This value of WIP was computed by multiplying the flowdays times the daily number of wheels produced (10 x 50 = 500). The WIP goal was later revised to 400 to correspond with the 40 wheels per day production goal.

Operating Expense. The measure of operating expense (OE) was not addressed by the PAT for this application of TOC because it was assumed that OE would remain constant. The PAT's guidelines were that no capital expenditures or reduction in personnel would result from the implemented changes.

Interview Responses to Performance Measures. Interviewees were asked if the measures of wheels produced, wheel flowdays, and wheel WIP were accurate measures of the division's performance. Twelve of 18 respondents provided unqualified support for using the measures for evaluating performance. An additional six respondents agreed with the use of the measures, but commented that they were "good on average", of questionable accuracy "due to AWP (awaiting parts)", and not "in line with AF supportability [measures]."

Reported Performance Success.

The implementation of the TOC principles in the wheel repair process of the Landing Gear Division were reported by the PAT as having resulted in increased throughput and reduced flowdays and WIP (Mackliet, 1992:3).

Throughput Increase. A 38% increase in throughput was reported as a result of implementing the TOC principles. The percentage increase in throughput was calculated as the difference in one quarter's production before implemented process changes as compared to one quarter's production after process changes. The quarters used in the calculation were judged to be "typical". The researchers were unable to obtain the raw data inputs to reconstruct the computation of the reported improvement in throughput.

Flowdays Decrease. A 75% decrease in flowdays was reported as a measure of successful TOC implementation. The percentage was based on an analysis of average wheel flowdays (40 days) before implemented process changes compared to the 10 flowdays goal set by the PAT. The 40 flowdays measure was a weighted average of the total processing times for 12 wheel types reported on AFLC Forms 958, Work Control Document, over approximately a one year period. The processing times were measured on both inner and outer wheel halves and an average was calculated to arrive at a whole wheel flowday time. These 12 types comprised approximately 80% of the total repair workload during the period and the weight was based on the relative frequency of workload volume of each wheel type. The researchers obtained summary data of the individual wheel flowday times; however, supporting raw processing times, the time period covered, and the workload volumes used in the computation were unavailable.

WIP Decrease. A 72% reduction in wheel WIP was associated with the TOC implementation. This percentage was computed from an average daily WIP count of approximately 1800 wheels before implemented process changes as compared to the goal of 500 wheels of average daily WIP set by the PAT. The raw data to support the WIP percentage reduction and the time period that it occurred were unavailable.

How Was Performance Success Defined and Measured?

Limitations. The researchers investigated definitions and measures of performance that could be examined to validate the nature and extent of TOC implementation success in the wheel repair process in terms of throughput, inventory, and operating expense. The definitions were limited by the availability of data due to the following reasons: 1) the initial low visibility and fanfare of the PAT efforts created no incentive to retain historical data files; 2) the manual record keeping of unofficial forms like the "Daily Wheel Status/Inventory" report that was used as an internal tracking worksheet to identify and resolve daily processing problems were perceived as having little or no historical importance; and 3) the possibility that recorded information on improvement efforts and results may not have been retained due to the competitive bidding process.

Throughput. Goldratt's definition of throughput is "The quantity of money generated by the firm through sales over a specified period of time" (Goldratt, The Goal, 1992:36). The scope of the wheel repair process was limited to the area of responsibility of the Production Unit within the Landing Gear Division, and the quantity of wheels produced each quarter was based on meeting the negotiated wheel requirements. Therefore, an alternate definition of throughput that retained the limited scope as viewed by the PAT, but considered the negotiated requirement, was chosen by the researchers. Throughput was defined as the quantity of wheels produced to meet quarterly negotiated requirements. Wheels produced in excess of the negotiated requirement would not be counted as "produced", but instead retained within the repair process as finished goods inventory. Conversion of the wheel quantities to dollars would not provide an improved throughput measure since the Production Unit produces wheel quantities to meet negotiated quantities irrespective of the individual wheel sales price or the resulting net revenue achieved.

Inventory. Inventory is defined by Goldratt as "the quantity of money invested in materials that the firm intends to sell" (Goldratt, The Goal, 1992:36). The measures of inventory defined by the PAT were the total quantity of wheel WIP and the average wheel flowdays through the process. As noted earlier in the chapter, wheel WIP counts were used to monitor scheduling performance on an informal daily worksheet; however, they were not retained for historical purposes. This data availability limitation resulted in the researchers operationalizing inventory as wheel flowdays. The flowday measure of inventory is directly related to WIP and is a function of induction, production, and buffer inventories. If the induction and production rates are maintained at similar rates and the buffer inventories in the process are small, then the flowdays multiplied by the daily average inductions will come close to equaling the amount of WIP in the system. The comment above on dollar conversion stated for throughput also applies to the WIP measure for inventory.

Operating Expense. Operating expense is defined by Goldratt as "the quantity of money spent by the firm to convert inventory into throughput over a specified period of time" (Goldratt, The Goal, 1992:36). The wheel PAT did not operationalize this definition due to the initial guidelines set by management as noted earlier in this chapter. The researchers investigated operationalizing operating expense as overtime dollars spent, operations overhead costs, and general and administrative costs for the wheel repair activities of the Production Unit. These data were found to be unusable because they were aggregated at a Resource Control Center (RCC) level that included the repair on struts and brakes, as well as wheels so that they could not be separated for analysis.

Summary

Chapter IV addressed what OO-ALC/LIL did to implement TOC (IQ #1), their performance measures and goals, and reported performance success. The performance of the Landing Gear Division's wheel repair process before TOC concepts were implemented was discussed in general terms (IQ #3). Finally, the chapter included a discussion of how the researchers define and measured performance success. Chapter V presents the case analysis and findings.

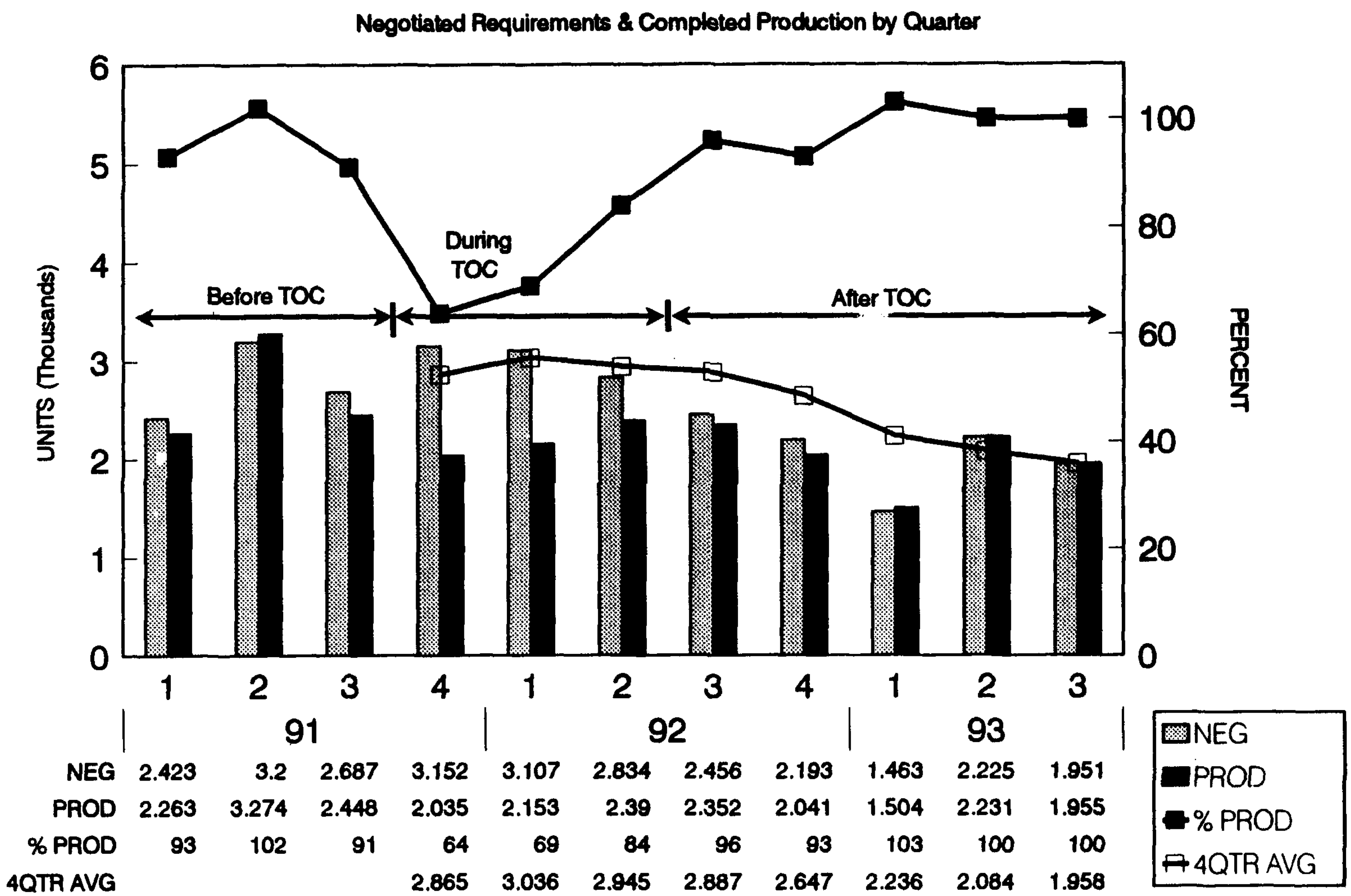
V. Analysis and Findings

The previous chapter established what was done at OO- ALC/LIL to implement TOC (IQ #1), how performance success was defined (IQ #2), and what general performance was prior to TOC. The next task of the case analysis is to address how performance changed after implementing TOC and examine the likelihood that changes in performance are attributable to the implementation of TOC concepts. Finally, unique features of the remanufacturing environment will be discussed in terms of how they affected TOC implementation.

Performance Before and After TOC Implementation

Analysis and findings related to performance will focus on an evaluation of available before and after TOC implementation data for the categories of throughput and inventory as operationalized by the researchers to determine what changes in performance occurred. (As stated previously, vigorous attempts to collect OE data were unsuccessful.)

Throughput Performance. The measure of throughput performance was defined as "the quantity of wheels produced to meet quarterly negotiated requirements." Data were obtained from OO-ALC/LICD on this measure of throughput for the period from the first quarter of FY91 to the third quarter of FY93. The researchers analyzed this data using simple summary statistics and presented the data in the form of a dual Y-axis side-by-side bar and line chart with inserted data table. Figure 3 shows this chart with historical units of negotiated wheel requirements and units of completed wheel production for 11 quarters. In addition, a percentage of completions to negotiated requirements



	91 Q1	91 Q2	91 Q3	91 Q4	92 Q1	92 Q2	92 Q3	92 Q4	93 Q1	93 Q2	93 Q3
NEG	2.423	3.2	2.687	3.152	3.107	2.834	2.456	2.193	1.463	2.225	1.951
PROD	2.263	3.274	2.448	2.035	2.153	2.39	2.352	2.041	1.504	2.231	1.955
% PROD	93	102	91	64	69	84	96	93	103	100	100
4QTR AVG				2.865	3.036	2.945	2.887	2.647	2.236	2.084	1.958

FISCAL QUARTERS

Figure 3. Historical Wheel Production

and a four quarter moving average of negotiated requirements were computed and are shown on the chart.

The first three quarters of FY 91 were considered before TOC implementation, the next three quarters (FY91-4 to FY92-2) were during TOC implementation and the remaining quarters (FY92-3 to FY93-3) were after TOC implementation. The three-quarter average of wheel production before TOC was 2662 units (FY91-1/2/3). After TOC implementation, all succeeding quarters of wheel production were less than this three-quarter average. Thus, throughput decreased after TOC implementation. However, negotiated wheel requirements decreased at a faster rate, as reflected in the higher percentages of actual production against negotiated requirements (103%, 100%, and 100% of requirements met in FY93-1/2/3, respectively). Further evidence of this decline in workload can be seen over the 11 quarter period in which there was a downward trend in negotiated wheel requirements as depicted by the four quarter moving average. The decline in negotiated wheel requirements was largely due to a decrease in the funding of depot repair actions, not only for aircraft wheels, but for all commodities in general.

Inventory Performance. The measure of inventory performance was defined as "wheel flowdays." Wheel flowdays data from before TOC implementation were obtained by the researchers from OO-ALC/LICT. These data consisted of the flowday values for the average repair cycle time of 12 weapon system wheel types used by the PAT to compute a 40 flowdays aggregate weighted average. The discussion of the source and characteristics of these data are in Chapter 4 under the heading "Reported Performance Success - Flowdays Decrease." As noted in that discussion, the data of workload volumes by wheel type used to compute the weights were not available. The wheel flowdays data after TOC implementation were obtained from OO-ALC/LILP in the form of an informal "Wheel Flowdays Report" that covered a period from 1 January 1992 to 31 August 1992. Average flowdays were summarized on the report from AFLC Forms 958, Work Control Documents, for 28 weapon system wheel types repaired during the period.

The researchers analyzed the flowdays data using simple summary statistics, data tables, and a graph. Two separate analysis procedures were performed to obtain different perspectives of the nature and extent of the flowdays performance changes. The first analysis was a direct comparison of individual flowdays by weapon system wheel type, and the second analysis was to compute an aggregate weighted average comparable to the flowdays measure reported by the wheel PAT.

Individual Flowdays. Flowdays data of the 12 weapon system wheel types from time periods before and after TOC implementation (those that reportedly comprised over 80% of the workload volume) were analyzed by direct comparison of the individual before and after values. A percentage change in the values was computed by taking the difference of before flowdays minus after flowdays and dividing by the before value (multiplied by 100 to obtain percent). Table 3 shows this comparison. "Flowdays After" values for the F111 and F4 weapon system nose wheels were not available for comparison to the before flowdays because of the absence of workload for those two types of wheels during the time period after TOC implementation. Analysis of the available comparisons indicated that all weapon system wheel types experienced a decrease in flowdays from the time period before TOC implementation to the time period after TOC implementation. The percentage of change in flowdays by weapon system wheel type ranged from -47% (decrease) to -79% (decrease).

Table 3. Comparison of Wheel Flowdays Before and After TOC

Weapon System	Wheel Type	Flowdays Before	Flowdays After	Percent Change
F111	NOSE	51.4	N/A	N/A
KC135	NOSE	51.2	11.0	-79%
F16	MAIN	48.5	20.0	-59%
F111	MAIN	46	16.0	-65%
C5	MAIN	41.2	12.0	-71%
F4	NOSE	29	N/A	N/A
B52	MAIN	28	12.0	-57%
KC135	MAIN	25	10.0	-60%
F15C/D	MAIN	23.7	12.0	-49%
C5	NOSE	22.4	11.0	-51%
C141	NOSE	20.5	9.0	-56%
C141	MAIN	17	9.0	-47%

Aggregate Weighted Average Flowdays. To analyze individual weapon system flowdays data in the form of an aggregate weighted average value, a weight factor of workload volumes was constructed. Eight quarters of wheel production data for all weapon system wheel types were obtained from OO-ALC/LILA. The eight quarters of wheel production represented two separate time periods: four quarters before TOC implementation (FY90-3 through FY91-2) and four quarters after TOC implementation (FY92-2 through FY93-1). An average quarterly value of each set of production data was computed. Table 4 shows the four quarters of wheels produced and the quarterly average before TOC implementation. Similarly, Table 5 shows the four quarters of wheels produced and the quarterly average after TOC implementation. To reduce both of these data sets to show one average quarterly production value per weapon system wheel type per data set, substitutable NSNs were consolidated to a single weapon system wheel type. The consolidated weapon system list was sorted in descending order by production volume. Table 6 shows the rank order of weapon system wheel types by production volume both before and after TOC implementation. The data of Table 6 provided the basis for establishing the weight factors for the flowdays.

Weighted Flowdays Before TOC. To compute an aggregate weighted average flowdays figure for the period before TOC implementation, the same 12 weapon system wheel types used by the PAT for computing the reported 40 flowdays were selected. Table 7 shows these wheel types with the average quarterly production extracted from Table 6 (before TOC production) and the individual flowdays from the period before TOC implementation as described above. The production of the 12 wheel types comprises 85% of the total average quarterly production (2454 of 2881 wheels produced). Weight

Table 4. Wheels Produced Before TOC

W/S	Type	NSN	FY 90-3	FY 90-4	FY 91-1	FY 91-2	Ave Qtr
A10	MAIN	16300012257451	27	13	2	25	17
A10	NOSE	1630005969637	57	61	21	68	52
A7	MAIN	1630010159879	13	29	11	18	18
A7	MAIN	1630011392892	17	30	17	14	20
A7	NOSE	1630000752003	5	3	3	7	5
B1B	MAIN	1630011829879	0	49	13	25	22
B1B	NOSE	1630011659072	0	0	2	1	1
B52	MAIN	1630000542557	0	0	8	1	2
B52	MAIN	1630009009739	64	33	17	24	35
B52	MAIN	1630002420942	68	12	84	50	54
B52	MAIN	1630012286043	316	0	90	240	162
C130	MAIN	1630009658700	10	7	0	0	4
C130	MAIN	1630010385126	11	31	69	16	32
C130	NOSE	1630009141329	8	6	0	3	4
C130	NOSE	1630008961212LC	1	0	0	0	0
C130	NOSE	1630009141328	72	38	112	119	85
C130	NOSE	1630010140656LC	8	0	0	4	3
C141	MAIN	1630011326400	124	264	123	167	170
C141	MAIN	1630011253957	123	139	16	228	127
C141	MAIN	1630010506139	53	15	30	30	32
C141	MAIN	1630004534893	35	72	30	203	85
C141	NOSE	1630000816687	30	67	50	20	42
C5	MAIN	1630011826267	665	480	231	383	440
C5	NOSE	1630002861879	118	0	95	90	76
E3A	MAIN	1630010098474	0	0	7	3	3
F100	NOSE	1630000874924	0	0	1	1	1
F106	MAIN	1630007828521	0	0	3	4	2
F111	MAIN	1630001576723	42	65	98	70	69
F111	MAIN	1630008329087	25	40	21	5	23
F111	NOSE	1630009414191	5	0	0	0	1
F111	NOSE	1630008430965	11	2	14	10	9
F15	MAIN	1630011375742	74	13	9	100	49
F15	MAIN	1630010585912	157	143	90	245	159
F15	MAIN	1630011414695	11	28	43	86	42
F15	MAIN	1630012251893	0	0	0	4	1
F16	MAIN	1630012523593	0	7	0	9	4
F16	MAIN	1630010389239	508	240	384	318	363
F4	MAIN	1630004463778	170	81	0	0	63
F4	NOSE	1630007300126	45	25	63	51	46
F4	NOSE	1630008521432	61	90	42	40	58
F5	NOSE	1630010555056	5	8	0	7	5
KC135	MAIN	1630000139129	123	124	154	149	138
KC135	MAIN	1630004927144	212	216	93	330	213
KC135	NOSE	1630004210319	65	158	123	96	111
KC135	NOSE	1630008873207	37	92	4	10	36

Table 5. Wheels Produced After TOC

W/S	Type	NSN	FY 92-2	FY 92-3	FY 92-4	FY 93-1	Ave Qtr
A10	MAIN	16300012257451	55	143	263	62	130
A10	NOSE	1630005969637	55	80	75	70	70
A7	MAIN	1630010159879	13	0	0	0	3
A7	MAIN	1630011392892	11	5	0	0	4
A7	NOSE	1630000752003	1	0	0	0	0
B1B	MAIN	1630011829879	126	106	122	75	107
B1B	NOSE	1630011659072	17	22	20	22	20
B52	MAIN	1630000542557	0	0	3	0	0
B52	MAIN	1630009009739	8	13	13	2	9
B52	MAIN	1630002420942	24	35	52	15	31
B52	MAIN	1630012286043	161	143	73	58	108
C130	MAIN	1630010385126	33	42	1	0	19
C130	NOSE	1630009141329	3	6	3	6	4
C130	NOSE	1630009141328	44	11	8	20	20
C130	NOSE	1630010140656LC	5	1	2	0	2
C141	MAIN	1630011326400	100	23	75	59	64
C141	MAIN	1630011253957	37	46	19	15	29
C141	MAIN	1630010506139	17	43	10	16	21
C141	MAIN	1630004534893	125	59	33	119	84
C141	NOSE	1630000816687	63	28	2	0	23
C5	MAIN	1630011826267	316	181	100	203	200
C5	NOSE	1630002861879	95	1	5	20	30
E3A	MAIN	1630010098474	13	6	0	0	4
E3A	NOSE	1630010109337	2	0	0	0	0
F100	MAIN	1630009000725	2	2	0	0	1
F106	MAIN	1630007828521	27	28	19	0	18
F106	NOSE	1630008963570	9	9	4	5	6
F111	MAIN	1630001576723	0	0	0	5	1
F111	MAIN	1630008329087	3	13	3	0	4
F15	MAIN	1630011375742	114	51	50	93	77
F15	MAIN	1630010585912	161	132	91	83	116
F15	MAIN	1630011414695	8	2	0	0	2
F15	MAIN	1630012251893	13	4	25	6	12
F15	NOSE	1630010716112	41	27	2	0	17
F16	MAIN	1630013173318	236	297	333	157	255
F16	MAIN	1630012523593	8	7	9	20	11
F16	MAIN	1630010389239	29	82	12	114	59
F4	NOSE	1630007300126	1	0	39	5	11
F4	NOSE	1630008521432	60	77	49	41	56
F5	MAIN	1630001398476	0	1	2	0	0
F5	MAIN	1630010416012	0	1	0	0	0
F5	NOSE	1630010555056	0	1	0	0	0
KC135	MAIN	1630000139129	109	45	7	2	40
KC135	MAIN	1630004927144	289	512	228	95	281
KC135	NOSE	1630004210319	43	64	14	0	30
KC135	NOSE	1630012947958	75	24	43	35	44
KC135	NOSE	1630008873207	5	25	19	22	17
T33	MAIN	1630004063998XW	39	34	18	0	22

Table 6. Rank Order of Wheels Produced Before and After TOC

Produced Before TOC			Produced After TOC		
Weapon System	Wheel Type	Ave Qtr Produced	Weapon System	Wheel Type	Ave Qtr Produced
C5	MAIN	440	F16	MAIN	325
C141	MAIN	414	KC135	MAIN	321
F16	MAIN	367	C5	MAIN	200
KC135	MAIN	351	C141	MAIN	198
B52	MAIN	253	B52	MAIN	148
F15C/D	MAIN	159	A10	MAIN	130
KC135	NOSE	147	F15C/D	MAIN	116
F4	NOSE	104	B1B	MAIN	107
C130	NOSE	92	KC135	NOSE	91
F111	MAIN	92	F15A/B	MAIN	79
F15A/B	MAIN	91	A10	NOSE	70
C5	NOSE	76	F4	NOSE	67
F4	MAIN	63	C5	NOSE	30
A10	NOSE	52	C130	NOSE	26
C141	NOSE	42	C141	NOSE	23
A7	MAIN	38	T33	MAIN	22
C130	MAIN	36	B1B	NOSE	20
B1B	MAIN	22	C130	MAIN	19
A10	MAIN	17	F106	MAIN	18
F111	NOSE	10	F15	NOSE	17
F5	NOSE	5	F15E	MAIN	12
A7	NOSE	5	A7	NOSE	7
E3A	MAIN	3	F106	NOSE	6
F106	MAIN	2	F111	MAIN	5
F100	NOSE	1	E3A	MAIN	4
F15E	MAIN	1	F100	MAIN	1
B1B	NOSE	1			2062
		2881			

Table 7. Wheel Flowdays Before TOC

Weapon System	Wheel Type	Ave Qtr Produced	Weight Factor	Flowdays Before	Weighted Flowdays
C5	MAIN	440	17.9%	41.2	7.4
C141	MAIN	414	16.9%	17	2.9
F16	MAIN	367	15.0%	48.5	7.3
KC135	MAIN	351	14.3%	25	3.6
B52	MAIN	253	10.3%	28	2.9
F15C/D	MAIN	159	6.5%	23.7	1.5
KC135	NOSE	147	6.0%	51.2	3.1
F4	NOSE	104	4.2%	29	1.2
F111	MAIN	92	3.7%	46	1.7
C5	NOSE	76	3.1%	22.4	0.7
C141	NOSE	42	1.7%	20.5	0.3
F111	NOSE	10	0.4%	51.4	0.2
		2454	AGGREGRATE WEIGHTED AVERAGE FOWDAYS		32.8

factors were computed from the relative frequency of the produced values. The weight factors were multiplied by the individual flowdays to derive the value that each wheel type contributes to an aggregate weighted average flowdays. The summation of the column of contributed values provides an aggregate weighted average of 32.8 flowdays.

Weighted Flowdays After TOC. To compute an aggregate weighted average flowdays for the period after TOC implementation, the top 12 weapon system wheel types that had the greatest amount of production based on the quarterly average production from Table 6 (after TOC production) were selected, with an exception. The twelfth highest production on Table 6 was the F4 nose wheel, but no corresponding flowdays were recorded by OO-ALC/LILP. Therefore, the next highest wheel production, the C5 nose, was selected as the twelfth wheel type. Table 8 shows these wheel types with the average quarterly production extracted from Table 6 and the individual flowdays for the period after TOC implementation as described above. Production of these 12 wheel types comprised 88% of the total average quarterly production for the period after TOC implementation (1815 of 2062 wheels produced). The same procedure as applied above for the computation of the aggregate weighted average flowdays before TOC implementation was followed. Weight factors were computed from the relative frequency of the produced values. The weight factors were multiplied by the individual flowdays to derive the value that each wheel type contributed to an aggregate weighted average flowdays. This column of contributed values was summed and resulted in an aggregate weighted value of 13.2 flowdays.

Flowdays Summary. Individual flowdays for the 12 weapon system wheel types that made up the majority of the wheel repair workload all showed a

Table 8. Wheel Flowdays After TOC

Weapon System	Wheel Type	Ave Qtr Produced	Weight Factor	Flowdays After	Weighted Flowdays
F16	MAIN	325	17.9%	20	3.6
KC135	MAIN	321	17.7%	10	1.8
C5	MAIN	200	11.0%	12	1.3
C141	MAIN	198	10.9%	9	1.0
B52	MAIN	148	8.2%	12	1.0
A10	MAIN	130	7.2%	13	0.9
F15C/D	MAIN	116	6.4%	12	0.8
B1B	MAIN	107	5.9%	23	1.4
KC135	NOSE	91	5.0%	11	0.6
F15A/B	MAIN	79	4.4%	11	0.5
A10	NOSE	70	3.9%	11	0.4
C5	NOSE	30	1.7%	11	0.2
		1815	AGGREGRATE WEIGHTED AVERAGE FLOWDAYS		13.3

decrease from the period before TOC implementation to the period after TOC implementation in the range of 47% decrease to 79% decrease. Additionally, the aggregate weighted average flowdays before TOC implementation of 32.8 dropped to 13.3 flowdays after TOC implementation. This change in aggregate weighted average flowdays represents a 59% decrease. These flowdays findings represent the strongest data available to demonstrate that performance did improve after TOC implementation. The graph in Figure 4 summarizes both individual flowdays and aggregate weighted average flowdays.

TOC and Changes in Performance

The purpose of this section is to 1) establish that TOC was implemented in the landing gear division, and 2) relate changes in performance to TOC implementation (IQ #4).

Was it TOC? An analysis of the case write-up presented in Chapter IV, which describes what was done at OO-ALC/LIL to implement TOC, and comparison with the literature reviewed in Chapter II about traditional TOC implementation demonstrates that Ogden implemented TOC concepts using the five focusing steps of TOC.

Identification of the Constraint. Simons and Moore state that constraints can be found in a variety of ways, to include examining process flows (rough cut capacity) and looking for visible backlogs of inventory such as the landing gear division's PAT did. In addition, they compared the capacity of the resource which they initially believed to be the constraint (the machine shop - specifically the shaper) with the demand placed on it to validate their belief as Simons and Moore suggest (Simons and Moore, 1992:2). In doing so, they found that the shaper was actually a capacity constrained resource (CCR) which

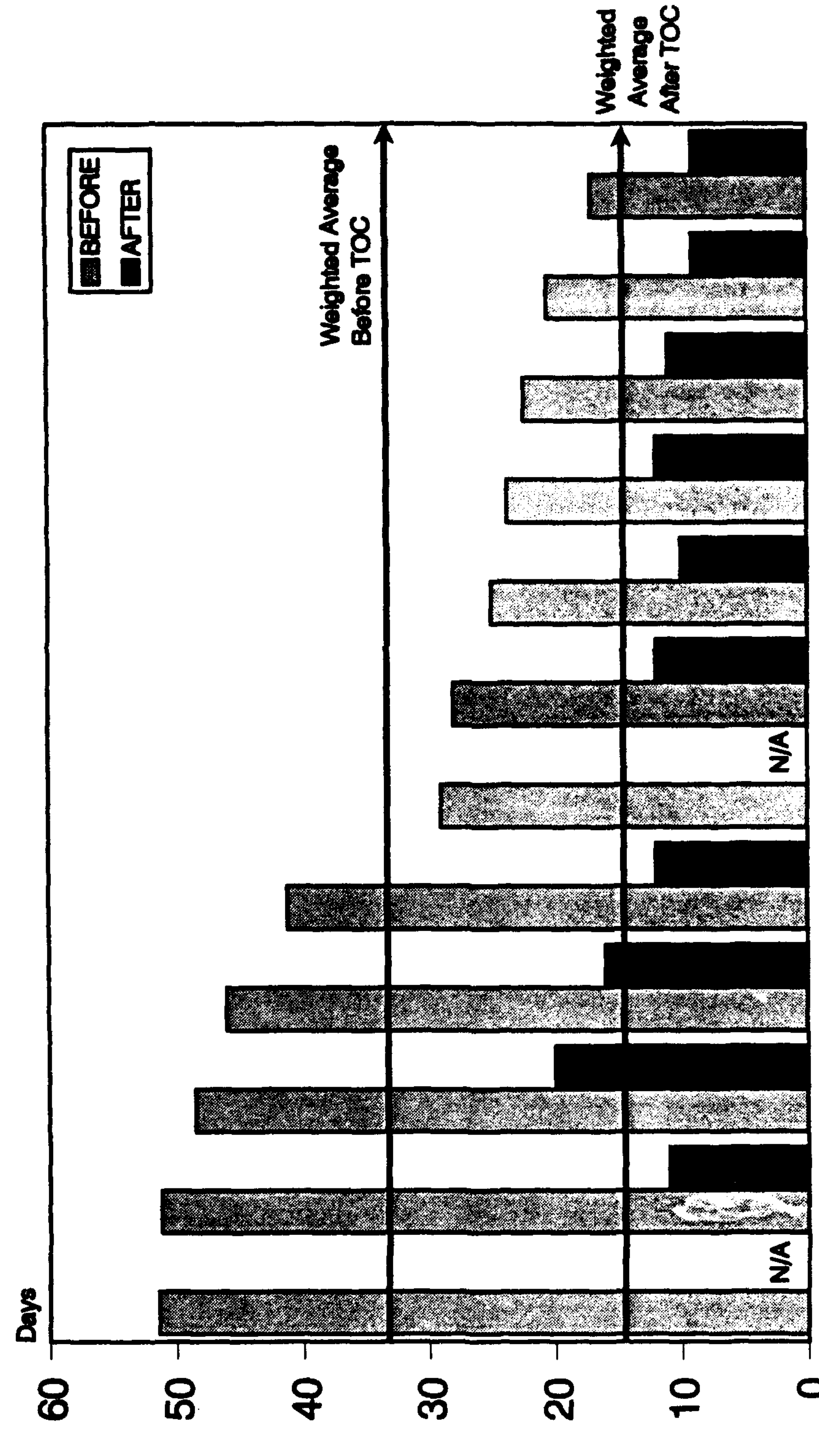


Figure 4. Summary of Wheel Flowdays Before and After TOC

if not properly managed could become a system constraint because of the long process times for F-15, F-16, and A-10 main wheels. The same was true of the paint line which appeared to be a constraint following the shaper. It also was a capacity constrained resource which had to be carefully managed due to the different physical sizes of the wheels and the amount of space they occupied on the conveyer rack.

In Theory of Constraints, Goldratt states that in manufacturing it is common to find that the constraint is a production policy constraint as in The Goal. In The Goal, the oven and the NCX-10 did not really lack the capacity required to meet the demand. The company did not have to buy a new oven or NCX-10, but instead, they had to change some of the production policies that were employed in the plant (Goldratt, Theory of Constraints, 1990:6). The Landing Gear Division PAT experienced a similar situation in dealing with policy and procedural issues which were constraining the system. Although the PAT addressed these policy and procedural issues as preparatory actions before "officially" beginning the five focusing steps, they had actually discovered policy constraints and by changing them, had elevated them. The absence of specific induction rules related to the types and batch sizes of wheels scheduled on a daily basis turned the management of the shaper and subsequently, the paint line, into capacity constrained resources. When these resources were not properly scheduled they were likely to cause the flow of wheels through the system to deviate from the planned flow. In addition, their wheel mating policy flowed wheels through the system as halves until they were mated at the bearing cup installation operation, was causing a large backlog of WIP in front of this operation. Similarly, the lack of induction rules allowed wheels into the system whether parts were available or not, causing WIP to backlog at assembly.

Exploitation. When procedures and policies are constraining the system, using these procedures and policies as they are to get as much out of the system as possible may be the answer to exploitation according to Simons and Moore (Simons and Moore, 1992:4). In Ogden's case, they revised their constraining internal policies and procedures, thereby skipping to the fourth focusing step of TOC - the elevation step. The new scheduling policy was based on scheduling a wheel mix and lot sizes through the system which would not saturate the shaper or the paint line. This was an attempt at DBR scheduling in which Ogden treated the management of the shaper as the drum, located a one day time buffer in front of it, and tied the drum back to induction by scheduling a wheel mix and lot sizes that did not saturate this resource (or the paint line). This scheduling policy improved performance by regulating the amount of WIP in the system, resulting in a smoother flow and less overall wheel flowdays. The new induction policy dictated that no wheel that was not parts supportable would be inducted into the system. Pre-kitting allowed this policy to be implemented. This induction policy improved performance by reducing the levels of WIP. This was accomplished by not allowing wheels in the system that would be delayed (thereby increasing flowdays) from processing for lack of parts. Finally, the wheel mating policy was revised so that wheels were mated at E & I and traveled together through the repair process. This new wheel mating policy also enhanced performance by reducing the WIP levels (decreasing flowdays) of wheels that were previously idle in the system awaiting mated halves.

In addition to skipping from exploitation to elevation by revising constraining procedures and policies, the landing gear division accomplished three exploitation actions to include moving the helicoil removal step from the machine shop to disassembly (3 interview responses), reducing setup time for the shaper (Bennett, LILP Letter, dated 21 Jan 92), and rearranging the machine shop into first go and second go lines (14 interview responses). These actions were taken to ensure that the machine shop shaper (a CCR) was being used as intelligently as possible as Simons and Moore suggest (Simons and Moore, 1992:3). These exploitation actions improved performance by allowing the shaper to have more production time and thus, accelerating the production of output which reduces flowdays, thereby reducing WIP.

Subordination. Subordination involves trying to use everything else in the system in a manner which supports the effectiveness of the constraint, according to Simons and Moore (Simons and Moore, 1992:3-4). With OO-ALC/LIL, subordination involved scheduling a wheel mix and lot sizes which ensured that the shaper and the paint line were not saturated. In effect, the other resources were subordinated to this schedule by processing no more than the daily production goal of the wheel mix and lot sizes as first inducted. This scheduling allowed for the intelligent management of the shaper and the paint line. According to Simons and Moore, doing things that help exploit the constraint can be considered active subordination (Simons and Moore, 1992:4). Thus, it is feasible to classify the movement of the helicoil removal operation as active subordination, as well as exploitation. The subordination activities improved the performance of the flowday measure by eliminating processing delays between resources because each resource's daily output became the next resource's daily input, achieving uninterrupted flow.

Elevation. Elevation generally involves lessening the severity of the constraint by increasing its capacity through the purchase of additional machines or hiring additional labor. Simons and Moore state that in the case of policy constraints, revising or eliminating the policy would be considered elevation (Simons and Moore, 1992:4). The landing gear division did not purchase additional machines or hire additional people to increase capacity, but as explained previously in the section which discussed exploitation, they did revise their scheduling, induction, and wheel mating policies and procedures and experienced improvements in terms of smoother flow and elimination of delays due to waiting for parts or wheel halves resulting in reduced flowdays and less inventory buildup. These actions were, in effect, elevation of internal policy constraints.

Recycling Through the Steps. The final focusing step of traditional TOC involves recycling through the previous four focusing steps to ensure that inertia does not set in. Simons and Moore state that these actions are important to continuous improvement for two reasons. First, a previous non-constraint could become a constraint after a cycle through the focusing steps. This was the case at Ogden when the paint line was identified as a CCR following the identification of the shaper as a CCR. Second, this recycling allows managers to continue to evaluate the circumstances in which a particular system operates. At Ogden, the PAT continues to meet weekly and the Quality Support section performs process flow analyses every few months. This is important to the division's effort for continuous improvement because of the dynamic workload demand caused by such environmental factors as defense drawdowns, reduced flying hours, base closures and funding level changes.

Summary of TOC Actions. OO-ALC/LIL followed the five focusing steps of TOC to identify capacity constraint resources. In addition, they used the TOC concepts of throughput and inventory to help develop a more effective global perspective on overall system performance and, in doing so, identified constraining policies and procedures. Through exploitation (moving the helicoil operation, reducing shaper set up time, and rearranging the machine shop), subordination (subordinating the other resources to the new scheduling procedures), and elevation (revising policies and procedures on scheduling, induction, and wheel mating); they ensured that the CCRs were being used as intelligently as possible, other resources were subordinated to the schedule which ensured that the CCRs were not saturated, and policies and procedures supported rather than constrained the system and the goal. Finally, the Landing Gear Division ensured that inertia would not set in by continuing to meet as a PAT and conducting process flow reviews every few months. The division is currently moving forward with applying TOC concepts to the brake and strut repair processes.

The Relation to Performance. The actions taken by OO-ALC/LIL in their wheel repair process improvement effort follow the five focusing steps of TOC implementation. According to Goldratt in The Race, the results of applying the five focusing steps of TOC are an increase in throughput (T), a decrease in inventory (I), and a decrease in operating expense (OE) (Goldratt, The Race, 1986:31).

Throughput. Based on the above analysis of produced workload data, actual throughput declined after TOC implementation. However, this decline in throughput is not attributable to the changes in the wheel repair process, but rather, is the result of a drop in market demand. Market demand is now the system constraint and has not been broken. Competition, the initial motivating factor that lead OO-ALC/LIL to process improvement using TOC concepts, is a way to elevate the market constraint. The comparison of negotiated to produced quantities demonstrates that the Landing Gear Division has improved their ability to meet quarterly negotiated requirements; however;

with the information available, concluding that the division's ability to meet these requirements was a result of TOC implementation would be speculation. Conversely, the researchers found nothing to support a finding that TOC was not a contributor to the increased ability to meet negotiated requirements.

Inventory. The researchers found that a logical connection could be made between TOC and the inventory performance changes. As noted previously, the revised scheduling policy improved performance by regulating the amount of WIP in front of the shaper and the paint line, resulting in a smoother flow and less overall wheel flowdays. The new induction policy improved performance by reducing the levels of WIP delayed for parts, thereby decreasing flowdays. Finally, the wheel mating policy enhanced performance by reducing WIP levels (decreasing flowdays) of wheels awaiting mated halves.

Operating Expense. As mentioned previously, the Ogden PAT did not operationalize operating expense measures because of the assumption that over the period of time of TOC implementation there would be no resulting changes in operational expense. The initial PAT guidelines were to incur no capital expenditures, nor institute any manpower decreases. Further, the researchers' efforts to operationalize operating expense as general and administrative costs, overhead costs, or overtime were unsuccessful. Thus, this operational measure plays no role in supporting whether performance changes are attributable to TOC.

Interview Responses. When asked if the changes in performance can reasonably be attributed to TOC implementation, 5 respondents answered with an unqualified yes. Twelve respondents answered yes, but qualified their answers by mentioning such things as JIT, increased management support, a changed philosophy, changes in mind sets and motivation, teamwork, and the opinion that TOC is common sense. None of these areas mentioned were viewed as confounds by the researchers because even though they were mentioned, none of these other management concepts surfaced as predominant guiding principles for conducting the improvement project.

When asked what other programs, projects, or organizational changes may have contributed to or influenced performance changes, the top 2 answers mentioned were Integrated Organizational Directorates (IOD) (6 responses) and reductions-in-force/layoffs (5 responses). Neither of these events were considered to be confounds. In fact, it was mentioned that IOD made it easier to make changes such as those required for TOC implementation because the reorganization provided more flexibility to directorates. If RIFs/layoffs had had a significant impact, it would probably have been most beneficial in terms of operating expense (not measured) and may even have run counter to improvements in throughput and inventory.

Remanufacturing and TOC Implementation

This section addresses investigative question #5 concerning the unique characteristics of remanufacturing and their effect on TOC implementation success. The relationship between the relevant literature reviewed in Chapter II and an analysis of the case study write-up of Chapter IV was evaluated and the researchers' findings are presented here.

General Process Characteristics. Demmy and Petrini suggest that the depot repair environment is well suited for DBR, the production scheduling application of TOC, due to the large number of job steps and the physical movement of material from one workcenter to another (Demmy and Petrini, 1992:11). The wheel repair process in the Landing Gear Division has 15 distinct operations with a primarily straight-line flow from one operation to another. This type of process facilitated the identification of potential resource constraints or capacity constrained resources because the PAT was able to evaluate the relative sizes of different accumulations of WIP in front of each resource in the system and to relate the WIP to a given resource. For example, fourteen of 18 interview respondents indicated that visibly checking WIP sizes in front of operations was the primary method that identified the machine shop as the perceived system constraint.

Disassembly. One of the unique characteristics of the remanufacturing environment of depot maintenance is disassembly, which can present processing conditions that may require the modification of the standard TOC procedures (Demmy and Petrini, 1992:11). Some of the peculiar aspects of the disassembly operation noted by four of 18 interview respondents referred to the variability in the amount of time required to process wheels. Comments such as "tear down is difficult for certain weapon systems", "disassembly can cause extra work if done incorrectly", "the condition of wheels is unknown", and "not all parts are attached" were pointed out as challenges that the disassembly operation may pose to the implementation of TOC principles. However, 12 of 18 interviewees said that there were no particular problems in implementing TOC that were caused specifically by the need for disassembly operation prior to repair.

Probabilistic Repair. Another of the unique characteristics of the remanufacturing environment is that of probabilistic repair, which can also present processing conditions that may require the modification of standard TOC procedures (Demmy and Petrini, 1992:11). The common problem noted by 10 of 18 interview respondents caused by probabilistic repair was the difficulty in determining the frequency of repairs in order to plan the flow and mix of wheels through the process. This variability of occurrence of types of repair procedures posed a particular challenge to implementing the TOC step of subordination, where planners had to schedule a mix and lot size of wheels that would flow through each of the repair operations while not exceeding the capacity of the capacity constraint resource.

Probabilistic repair also complicates the implementation of the first TOC focusing step of constraint identification. The researchers noted that the occurrence rates for probabilistic repair were a complicating factor in identifying the resource capacities by type of wheel processed. Occurrence data was a key factor in preparing a "weekly wheel workload constraint analysis" spreadsheet used by the PAT to identify the system's constraint. This 64 column by 45 row spreadsheet matrix of past operational time and demand data by process operation and wheel type demonstrated the analysis complexity that may be required to focus on a system's constraint.

A noteworthy response by an interviewee to the question on the problems posed by probabilistic repair was that it was a cause of a high number of equipment setups. In exploiting a constraint, TOC proponents emphasize the reduction of setup time so that more of the demand for smaller lot sizes can be met when a resource processes more than one type of product. Thus, exploiting activities in a probabilistic repair environment may require extra effort to seek ways to reduce equipment setup times.

Repair Parts. Demmy and Petrini identified delays in obtaining parts from depot supply as a unique characteristic of the remanufacturing environment that must be taken into consideration to successfully implement TOC. In particular, the lack of assurance of availability of repair parts and components must be factored into the sizing of buffer inventories (Demmy and Petrini, 1992:11). When asked what the problems were caused by the variability of the supply system, all 18 respondents stated that supply variability was, and is now, a problem causing the delay of wheel repair. Further, 14 of the 18 interview respondents identified pre-kitting of repair parts (establishing an assembly buffer) and the change in policy to only induct parts supportable wheels into the repair process (elevating a policy constraint) as two actions taken to deal with the parts variability problem.

The impact of probabilistic repair was linked to the parts supportability problem by one interviewee in response to the question on problems associated with probabilistic repair. This link was the difficulty in projecting the correct parts on the bill of materials due to the uncertainty of occurrences with probabilistic repair. The same issue of bill of material errors was cited by the OO-ALC/LIL Materiel Supportability Study as the largest contributor to supportability problems in the wheel repair process (LIL Materiel Supportability, 1991:147). Thus, the TOC concept of buffer management should be emphasized when applied to remanufacturing processes, specifically in the area of assembly buffers.

General Process Variability. Higher levels of uncertainty and slow information feedback are cited by Demmy and Petrini as factors in a remanufacturing environment that will require larger buffer inventories (Demmy and Petrini, 1992:11). However, the researchers noted that the only buffer inventories in the wheel repair process were the one day time buffer in front of the machine shop and the assembly buffer of kitted parts at the point of final assembly. The wheel repair process has numerous sources of variability, such as types of wheels, condemnation percentage, probabilistic repair, and parts supportability, that could be used to justify buffer inventories in front of resource operations experiencing the most variability. Since the system's true constraint is the market demand, i.e., negotiated quarterly requirements, all resources have sufficient "protective capacity" to increase output, if necessary, to complete their daily "buckets" of wheel mix and lot size for the next resource in the process sequence to have the necessary WIP inventory for the following day's production. In essence, the wheel repair process is a synchronous flow of wheels with few buffer inventories.

Another aspect of the general level of variability in the remanufacturing environment is that it does pose unique difficulties for management. Management's solutions to problems can take the form of policy directives that may result in system constraints. As noted in the case of the wheel repair process with unmated wheel halves, management policies to deal with the effects of the system's condemnation variability between inner and outer wheel halves was to process them separately through nearly the entire process. This policy was seen by the PAT as one that had to be revised because it did not align with the planned production of throughput when measured as whole wheels. The researchers suggest that the level of variability inherent in the remanufacturing process provides the catalyst for management to put in place policies that may constrain the system.

Summary

In this chapter the researchers analyzed and presented findings concerning performance before and after TOC implementation. It was established that TOC was implemented within the wheel repair process according to the five focusing steps. In addition, changes in flowdays were related to TOC implementation. Finally, the unique characteristics of remanufacturing that affect TOC implementation success were examined.

VI. Conclusions and Recommendations

The objective of this research was to validate the nature and extent of success in implementing TOC in the remanufacturing environment at the Ogden ALC Landing Gear Division. The researchers utilized the case study methodology to accomplish this objective. This chapter presents the conclusions of this research and recommendations for OO-ALC management, as well as recommendations for further research .

Conclusions

Implementation. TOC concepts were implemented at OO-ALC/LIL using the five focusing steps to identify and break several perceived system constraints. In addition, a form of DBR scheduling was established to create a synchronous flow of wheels through the repair process. It is important to note that this implementation of TOC concepts by the Landing Gear Division was a prototype effort of intentionally limited scope that only encompassed the wheel repair process. As such, only suboptimal results could be achieved in terms of improved weapons system supportability. This is supported by two findings. First, inputs to the system (wheel inductions) were limited to parts supportable wheels in an effort to reduce WIP in the repair process. However, this action did not solve the root problem of timely and accurate parts supportability: It only served to relocate the wheel WIP (and related flowdays) to reparable supply. Second, the outputs of the system (wheel production) were "sold to supply" to meet projected requisitions of the customer. However, these projections (negotiated wheel requirements) were not evaluated for accuracy as part of the process improvement project, and thus the potential existed for producing "finished goods" to become warehoused inventory that would not meet future customer requirements.

Defining the boundaries of the system to which TOC concepts will be applied has significant ramifications on the selection of measures for throughput, inventory, and operating expense and on the perception of local optimization relative to adjacent processes. As in the Ogden case, limiting the system's scope to the boundaries of process ownership facilitates decision making relative to the TOC steps of exploitation and subordination and, when the process has been improved, puts the process owner in a better position to highlight system constraints external to their areas of responsibility.

Performance Changes. In terms of validating the extent of success, only one tangible measure of inventory performance - flowdays - could be validated by the researchers. This measure of success was applicable to all weapon system wheel types and the 12 key weapon system wheel types evaluated (top 80+% of the workload volume) showed individual flowday reductions between 47% and 79%, with the aggregate weighted average flowdays decreasing approximately 60%. Since the flowdays measure has a direct relationship to WIP, the inference was that WIP experienced a comparable decrease.

The performance data of the throughput measure of production against negotiated requirements might have presented a conclusive argument for positive performance change had not the demand for wheels experienced a declining trend. However, it was noteworthy that the Production Unit was able to meet the negotiated requirement for three consecutive quarters in FY93.

The absence of TOC performance measures in terms of dollars of inventory (WIP) and operating expense only serve to demonstrate that existing systems need to be restructured to define and collect data in support of these measures so that further efforts at TOC implementation will be enhanced.

The intangible aspects of performance related to successful TOC implementation include improved communication, cooperation, and level of job involvement among participants. Reduced levels of WIP promoted an organizational team approach, as noted by the PAT, to deal with the increased interdependencies of workcenters.

Performance Attributable to TOC. The change in flowday performance can be logically linked to TOC implementation actions stemming from the five focusing steps. The elevating actions of the policy changes concerning induction of parts supportable wheels and wheel mating were directly responsible for the significant reduction in wheels sitting idle in the repair process and accumulating flowdays. The scheduling of a synchronized work flow and minimal time buffers also contributed to shorter process lead times and thus reduced flowdays. In addition, the fact that the division is pursuing other TOC implementation efforts with their brake and strut product lines demonstrates their belief that TOC was responsible for the positive changes experienced in the wheel repair process.

Unique Characteristics of Remanufacturing. Variability due to probabilistic repair and supply availability is the key unique characteristic of remanufacturing that impacts TOC implementation success. Variability adds to the complexity of constraint identification, exploitation, and subordination by introducing occurrence factors into the evaluation process. The uncertainty of supply availability presents the scheduler with a challenge to maintain an achievable schedule. In addition, variability in the wheel remanufacturing process had a logical connection to the management policies that were found to be constraining factors in the process. Policies and procedural constraints can be the more difficult types of constraints to identify and break to achieve TOC implementation success.

Recommendations

Recommendations for OO-ALC/LIL Management. Based on the findings of this research effort, it is recommended that management pursue changes in cost accounting and management systems and procedures that will enhance data collection related to the measures of throughput, inventory and operating expense. Data collection procedures should emphasize categorizing data by product lines and converting units into dollar measures. For TOC concepts to be fairly evaluated in their own terms, data must be available to operationalize the definition of TOC performance measures. It is also recommended that management actively seek more workload through competition to break the market constraint and fully utilize available production capacity in the wheel repair process.

Recommendations for Future Research. Three topics of research related to the Theory of Constraints may prove to be beneficial in enhancing the understanding of its potential in the depot remanufacturing environment. First, future research in the form of other case studies on TOC implementation would be useful in establishing a body of knowledge and predictive capability on the performance of TOC concepts in the depot remanufacturing environment. Second, future research should address the issue of breaking a market constraint in the DoD environment from the perspective of levels of defense based on external threat and finite defense budgets. Finally, future research may be helpful in TOC implementation by evaluating the criteria and considerations needed to determine the scope, and establish the definition, of the system to be improved.

Summary

The researchers met with moderate success in achieving the research objective, primarily due to the inability to obtain data that could be operationalized to the definitions of throughput, inventory, and operating expense. However, the TOC implementation in the Landing Gear Division at Ogden Air Logistics Center, Hill AFB UT was viewed by the researchers as successful. The TOC effort left a positive impression on the workforce that a proven tool now existed to enhance the competitive position of the organization. The experience of applying TOC to the wheel repair process provided a building block for future applications of TOC concepts.

Appendix A: Interview Instrument

BACKGROUND QUESTIONS:

1. What is your position title and your organization?

2. Which of the following three categories of TOC involvement do you fit?

   - involved from the beginning and still an active player
   - involved from the beginning and now working away from the area
   - not involved from the beginning, but now involved with TOC

IQ #1: What was done to implement TOC at OO-ALC/LIL?

1. What types of TOC training did you receive?

2. Were teams formed? If so, what type?

3. How was the project promoted and to whom?

4. Why was there a need to use TOC concepts in the Landing Gear Division?

5. Why was the wheel repair process selected to be improved?

6. What were the methods used to identify the major system constraint?

7. What was identified as the constraint?

8. What was done to exploit the constraint (exploit: fully utilized to work the most important things)?

9. What steps were taken to subordinate other resources to the constraint?

10. What actions were taken to elevate (increase levels of) constraint capacity?

11. What methods were used to place and size inventory buffers in the wheel repair process?

12. What methods were used to control the flow of reparable wheels inducted into the repair process?

13. What actions were taken to continue the improvement process (look for another constraint and recycle through the steps taken prior)?

IQ #2: How was performance success defined and measured?

1. Based on written documentation, it appears that management used the following indicators to judge successful performance: wheels in process, wheels sold per day, and wheel flowdays.

Do you feel that these are accurate measures of performance? Why or why not?

2. Are there other indicators which you feel are more accurate measures of success and if so, what are they?

IQ #4: Can the changes in performance be reasonably attributed to TOC implementation?

1. Can the changes in performance be reasonably attributed to TOC implementation?

2. What other programs/projects/organizational changes may have contributed to or influenced performance changes?

IQ #5: What are the unique characteristics of the remanufacturing environment which affect TOC implementation success?

1. What problems/challenges were caused by the need for disassembly prior to repair?

2. What problems/challenges were caused by the probabilistic nature of the repair process (repair operations/materials not known until item is inspected and failure identified)?

3. What problems/challenges were caused by the variability of the supply system (delays in obtaining material from depot supply)?

Appendix B: Summarization of Interviewee Responses

BACKGROUND QUESTIONS:

1. What is your position title and your organization?

   To maintain the anonymity of respondents, the answers to this question were not recorded in this summary.

2. Which of the following three categories of TOC involvement do you fit?

   - involved from the beginning and still an active player

     11 out of 18 or 61.11%

   - involved from the beginning and now working away from the area

     3 out of 18 or 16.66%

   - not involved from the beginning, but now involved with TOC

     3 out of 18 or 16.66%

   - not part of the formal team (added category)

     1 out of 18 or 5.55%

IQ #1: What was done to implement TOC/DBR at OO-ALC/LIL?

1. What types of TOC training did you receive?

   11 out of 18 or 61.11% had training

   Of the 11 trained, 2 or 18.18% had training at the outset.

Of the 11 trained, 3 received the Jonah Course, 6 received a one week TOC course, 2 received an overview from the division chief, 3 received DISASTER software training, and 1 received team building training.

7 out of 18 or 38.88% had no formal training

Of the 7 with no formal training, 2 or 28.57% received no training, 1 or 14.29% read books on TOC, and 4 or 57.14% were trained "on-the-job" as the implementation progressed.

2. Were teams formed? If so, what type?

18 out of 18 or 100% stated that a team or teams were formed.

11 out of 18 or 61.11% said one process action team (PAT) was formed.

6 out of 18 or 27.78% said one primary PAT team plus workcenter teams were formed.

1 out of 18 or 5.55% responded as not being part of a formal team.

3. How was the project promoted and to whom?

15 out of 18 or 83.33% responded that the project was promoted from management on down.

1 out of 18 or 5.56% responded that the project was not promoted.

2 out of 18 or 5.56% responded that they could not recall.

4. Why was there a need to use TOC concepts in the Landing Gear Division?

Response	No. of Times Mentioned
Excessive flowdays	9
Impending competitive bid	8
High WIP level	6

Response	No. of Times Mentioned
Poor scheduling	2
Division chief identified need	1

5. Why was the wheel repair process selected to be improved?

Response	No. of Times Mentioned
Impending competitive bid	14
Simplicity of the wheel repair process	8
High Level of inventory	3

6. What were the methods used to identify the major system constraint?

Response	No. of Times Mentioned
Visibility of cues	14
Analysis (capacities, flow processes, utilization, etc.)	9

7. What was identified as the constraint?

Response	No. of Times Mentioned
Machine shop, followed by the paint shop	13
Machine shop alone	3
Blast area	2
Cleaning area	1
Don't know	1

Of the 16 times that the machine shop was mentioned, the shaper was specifically mentioned 8 times.

8. What was done to exploit the constraint (exploit: fully utilize to work the most important things)?

Response	No. of Times Mentioned
Rearranged machines in the machine shop	14
Scheduled for the correct wheel mix and lot sizes	9
Moved some NDI inspections forward	6
Moved the helicoil removal step forward	3
Temporarily added labor shifts (2nd and 3rd shifts for the shaper and an early shift for the paint line)	3
Added carriers (20) to the paint line	2
Moved workers between assembly and disassembly	2
Straightlined induction (50 wheels)	1

9. What steps were taken to subordinate other resources to the constraint?

Response	No. of Times Mentioned
Don't know	9
Scheduled for the correct wheel mix/lot sizes	9

Response	No. of Times Mentioned
Inducted only parts supportable wheels into the system	1
Straightlined the production schedule (50 wheels)	1
Utilized first-in-first-out (FIFO) in plating	1

10. What actions were taken to elevate (increase levels of) constraint capacity?

Response	No. of Times Mentioned
Don't know	6
Added paint carriers	4
Elevation was not necessary	3
Scheduled for the correct wheel mix/lot sizes	2
Temporarily added labor shifts	2
Utilized FIFO in plating	1
Matched inboard and outboard wheel halves at E & I	1
Pre-kitted parts	1
Worked only what was scheduled	1

11. What methods were used to place and size inventory buffers in the wheel repair process?

Response	No. of Times Mentioned
Determined by daily capacity of constraint	9
Determined by what was constraints busy	2
Don't know	1
Didn't need	1

5 respondents specifically mentioned a machine shop buffer.

3 respondents mentioned a one-day buffer in all areas.

2 respondents mentioned a plating buffer.

1 respondent mentioned buffers wherever there was a constraint.

1 respondent mentioned an assembly buffer.

1 respondent mentioned a disassembly buffer.

5 respondents mentioned that buffer levels were now lowered or eliminated.

12. What methods were used to control the flow of reparable wheels inducted into the repair process?

Response	No. of Times Mentioned
Scheduled wheel mix/ lot sizes based on constraint	14
Inducted only parts supportable wheels	5
Straightlined induction (50 wheels)	3

Response	No. of Times Mentioned
Negotiations	2
Matched wheel halves at E & I	1
Don't know	1

13. What actions were taken to continue the improvement process (look for another constraint and recycle through the steps taken prior)?

Response	No. of Times Mentioned
Team continues to meet once per week	7
Other product lines currently being worked	5
Paint shop identified as a constraint after the machine shop	4
Don't know	3
Workcenter quality teams are still used	1
Quality Support looks at work flows every couple of months	1
As workloads change, the situation is re-evaluated	1

IQ #2: How was performance success defined and measured?

1. Based on written documentation, it appears that management used the following indicators to judge successful performance: wheels in process, wheels sold per day, and wheel flow days.

   Do you feel that these are accurate measures of performance? Why or why not?

Response	No. of Times Mentioned
Unqualified yes	12
Yes, but unsure of accuracy due to AWP	1
Yes, but suggests looking at other indicators as well	1
Good, on average	2
Adequate, but may not fall in line with AF supportability measures	1
Don't know because there is no system perspective that the right wheels are meeting demand	1

2. Are there other indicators which you feel are more accurate measures of success and if so, what are they?

Response	No. of Times Mentioned
Cost to achieve performance	3
Condemnation costs	2
Efficiencies (due to DCAA mentality)	1
Cost reductions	1
Manpower effectivity	1

Response	No. of Times Mentioned
Due date performance/ turn to demand	1
Induction dates/FIFO tracking	1
DMMIS might provide other indicators	1

IQ #4: Can the changes in performance be reasonably attributed to TOC implementation?

1. Can the changes in performance be reasonably attributed to TOC implementation?

Response	No. of Times Mentioned
Qualified yes	12
Unqualified yes	5

Qualifications mentioned:
- Just-in-time (JIT)
- Management support increased
- Philosophy changed
- Mindsets, motivation changed
- TOC provided a methodology for known needed improvements (common sense)
- Teamwork concept was at a peak

2. What other programs/projects/organizational changes may have contributed to or influenced performance changes?

Response	No. of Times Mentioned
Integrated Organizational Directorates (IOD)	6
Reduction-in-force (RIF)/ layoffs	5
None	4

Response	No. of Times Mentioned
DMMIS	2
Team building	2
Compressed work schedule	1
TQM	1
JIT	1
Materiel PAT	1

When impact was indicated, responses included:

Negative impact:

- IOD abolished Quality as separate entity and caused confusion
- RIF/layoffs caused perceived manpower shortages and affected morale

Positive impact:

- IOD made it easier to make changes by providing flexibility and helped with the customer requirements side (now under same direction)

IQ #5: What are the unique characteristics of the remanufacturing environment which affect TOC/DBR success?

1. What problems/challenges were caused by the need for disassembly prior to repair?

Response	No. of Times Mentioned
None	12
Tear down is difficult for certain weapon systems (time factor)	1
Disassembly needs to "buy in" more	1

Response	No. of Times Mentioned
Disassembly can cause extra work if done incorrectly	1
The condition of the wheels is unknown	1
Not all parts are attached	1
Workers reluctant to switch back and forth from assembly to disassembly	1

2. What problems were caused by the probabilistic nature of the repair process (repair operations/materials not known until item is inspected and failure identified)?

Response	No. of Times Mentioned
Difficult to determine frequency of occurrence of different repairs in order to plan the flow/mix (variability)	10
None	1
Don't know	4
Drove the need to be more flexible	2
Can't batch items	1
Required that inspection points be moved up front	1
Difficult to project bill of materials (BOM)	1
More setups required	1
Tolerances are critical	1

3. What problems were caused by the variability of the supply system (delays in obtaining material from depot supply)?

Every respondent stated that supply variability was and is now a problem.

10 respondents stated that supply variability was and still is a big problem (2 respondents classified it as the #1 problem).

Actions necessitated by this problem included:
- pre-kitting and inducting only what is parts supportable (mentioned 14 times)
- reclamation of usable parts (mentioned 3 times)
- renegotiations (mentioned 2 times)
- if parts were not available, they were not ordered and were dropped off the BOM making it inaccurate

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Vita

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REPAIR PROCESS IMPROVEMENT AT THE OGDEN AIR LOGISTICS CENTER, LANDING GEAR DIVISION: A CASE STUDY IN THE APPLICATION OF THE THEORY OF CONSTRAINTS

5. FUNDING NUMBERS

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12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

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13. ABSTRACT *(Maximum 200 words)*

This study explored the nature and extent of success that resulted from the implementation of the Theory of Constraints (TOC) in a depot repair environment. The actions taken to implement TOC were determined. Performance measures which defined success were identified and data were collected and summarized to demonstrate performance before and after implementation of TOC concepts. Improvements in flowdays and work-in-process (WIP) were determined to be attributable to the TOC effort. In addition, the unique characteristics of probabalistic repair and supply system variability were noted as those characteristics that posed the greatest challenges to implementing TOC in a remanufacturing environment. Despite these challenges, analysis revealed that the Landing Gear Division at Ogden Air Logistics Center (ALC) successfully implemented TOC concepts and improved performance within the wheel repair process in terms of the performance measures defined.

14. SUBJECT TERMS
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